

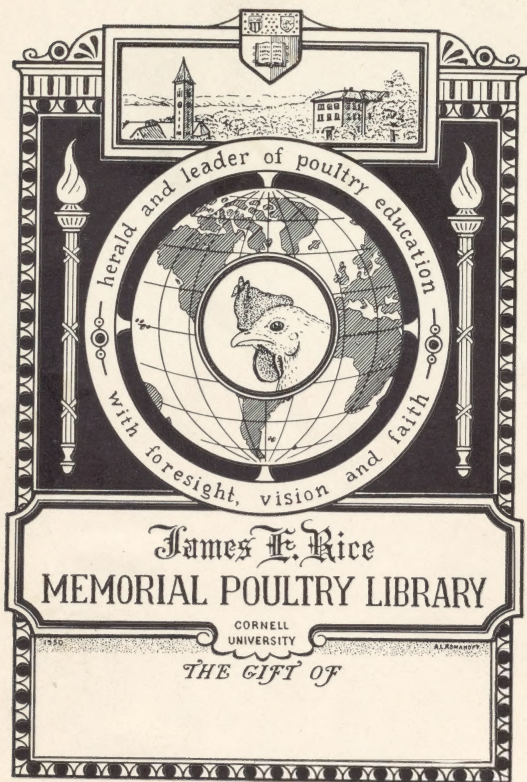
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*Incubation
AND
Its Natural Laws
BY
Chas. H. Cyphers*



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Incubation and its natural laws.



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INCUBATION

AND ITS

NATURAL LAWS

BY

CHARLES A. CYPHERS

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INTRODUCTION.

FIRST EDITION.

IT is with pleasure the author of this work puts away his experimental apparatus, lays aside his pen, and offers the results of his labors to those who are interested in the phenomenon of Incubation. During his initiation into the intricacies of artificial incubation he has felt, in common with many others, the want of a work which gave a comprehensive view of the subject, embracing the general principles common to both the natural and artificial process.

There have been many books that touched upon the subject, and others that pretended to treat on it, but the whole subject has not been encompassed. The developmental history of artificial incubation shows it to have been prosecuted by a series of haphazard experiments without seeking definite principles, and the literature on this subject could only give the knowledge thus obtained.

The incubation of an egg is the commencement of a life, and this phenomenon is consequently as complex as life. To treat the subject intelligently it is necessary to recognize this fact and discuss the various phenomena on the same broad basis. Therefore the physiological side of the subject has been given as comprehensive a presentation as space would permit; and undoubtedly to many of a lively mind, who have had some experience in artificial incuba-

tion, the solution of many of the heretofore perplexing questions will present themselves to the mind before arriving at the author's deductions.

In no instance has there been given as facts merely old views which have long passed current, but a digest of results obtained by independent research, observation, and experiments ; winnowing away the chaff of old speculative theories ; bringing out the remote and broader analogies connected with this most interesting phenomenon of organic life ; appropriating the advanced results of collateral science and making practical use of them in elucidation of the subject.

As many of the facts herein set forth have heretofore never appeared in print, and of which the reader cannot find corroboration in other poultry literature, he is respectfully asked to give the whole work a careful perusal before criticising the determinations the author has made, when the logic in the new application of the well-known physical laws will be appreciated, though they run counter to many of the old and accepted theories.

Preface, Third Edition.

After three years' correspondence with purchasers of this work who have altered over machines according to directions herein outlined, it is presumable the author has learned facts that were beyond his reach when experimenting in one cellar and with a limited number of machines.

It has been demonstrated very forcibly that many machines will not heat evenly without the aid of a cross-current of air, and therefore bottom ventilation is out of the question with those. Many machines naturally vary from three to six degrees over the area of the egg chamber, and therefore nothing will help them. Many cannot be regulated within two degrees, and the results are then uncertain. With a machine that does not vary two degrees in either the area of the egg chamber or regulation, better results can always be obtained with bottom ventilation than other systems of direct openings. This has been testified to by hundreds who have tried it since this publication was first issued.

I find there is little difference in the territorial location of a machine, but many operators place their machines where it is unfit to run an incubator—attics that are extremely hot in summer and cold in winter; cellars that are damp in the extreme; and out-buildings of all descriptions. For the best results, 65 degrees should be maintained the year around. This is not profitable for those using but a few machines, or practicable in summer farther south than Maine, but when possible place the machine in a comfortable room with plenty of sweet fresh air. More eggs are wasted on the large plants by chilling when running in a cold room in early winter than would pay for a little warmth. A thoroughly dry cellar is all right, but few cellars are dry, and for this reason I now advise placing a machine above ground. A one-story stone or brick building is preferable to any other, but it takes a season to dry out such a structure, and they therefore should be erected early in the spring. A ground-floor room can always be ventilated with greater ease than a cellar. Time was when there were no machines that would regulate above ground and under a varying temperature, and a cellar was necessary, but that time is past.

Where bottom ventilation has been adopted, I have found in the average cellar that no moisture was required until the 18th day; and sometimes not even then where the cellar was damp. I have even found a few places where it was necessary to increase the number of holes in the bottom to secure the proper air cell in the incubating egg. Those who have adopted bottom ventilation, however, and altered the amount of moisture and ventilation to suit the place of operation, have secured much better hatches than they ever did before.

In the past I have answered all letters of inquiry regarding the operation of the various makes of incubators, giving my time freely; but now having a machine of my own on the market, I feel my time belongs wholly to my customers, in whom I have a financial interest to see that they make a success of their poultry ventures. I am very glad to have been able to help many in the past, and am very thankful for the kind letters of thanks and appreciation received. Though I may not have time to reply, I shall always be happy to hear from those who have been benefited by a study of this work.

Incubation and its Natural Laws.

CHAPTER I.

THE HISTORY OF ARTIFICIAL INCUBATION.

THE art of artificially hatching hens' eggs has been known from the remotest ages. Though in Egypt tradition attributes the invention to the ancient priests of the Temple of Isis, it is impossible to determine at what period or to what nation the construction of the first incubator should be credited. The first authentic account we find of the early methods is in "The Voiage and Travaile of Sir John Maundeville, Kt.," in his description of the River Nile, Egypt, its geography, productions, etc., written some time previous to 1356, as a "solace" during his "wretched rest," on his return to England from the East, broken in health: "Also at Cayre (Cairo), that I spake of before, sellen men, commonly men and women of other lawe, as we done here bestes in the market. And there is a common hows in that cytee that is all fulle of smale furneys; and thidre bryngen wommen of the toun here eyren (eggs) of hennes, of gees, and of dokes, for to ben put in to the furneyses. And thei that kepen that hows covern hem with hete of hors dong, and outen henne, goos or doke or any other foul; and at the ende of three weeks or a monethe, thei comen agen and taken here chickens and norrische hem and bryngen hem forthe, so that alle the countre is fulle of hem. And so men don there bothe wyntre and somer." These hatching places at one time extended over Egypt, Damascus, Jerusalem and Samaria. They are now only found in Mausoura, in the village of Berma, situated in the Delta of the Nile. The Egyptians must have had a thorough knowledge of the details of their method, for we find those having ovens, or mammals, and making artificial hatching a business, giving

sixty newly hatched chicks in exchange for one hundred eggs.

The stories that reached France of the success of the Egyptians in this branch of rural economy created considerable interest at one time. One Florentine Duke imported an Egyptian director, and met with considerable success. In 1415 Charles VII. became interested, as did also Francis I., at Montrichard, about 1540. Bonneman, a physician of Nauterre, 1777, seems to have been the first to establish hatching ovens whereby the heat was generated with fire and diffused by a circulation of hot water. Though the stories of his establishment are undoubtedly of lusty growth, the fact remains that he had chickens all the year round, and supplied the Imperial Court of France in all seasons. The disastrous events of 1814 were the ruin of his establishment.

To John Champion, Berwick-upon-Tweed, England, 1770, however, probably belongs the credit of first hatching eggs by the aid of fire. He used a room through which passed two heated flues, the eggs being placed on a large, round table in the centre. He claimed that the incubation was performed as well, and as many of the eggs hatched, as if they had been set upon by a hen. He says: "The two flue places do not open into the hatching room, but into one adjoining, where the keeper sits and the coal is kept. By this means the eggs are free from smoke and dust, which they might otherwise be greatly injured by. The two rooms have a door communication that the keeper may every now and then visit the eggs, and see if they are in the proper degree of heat."

From this time on to 1846 little was accomplished, though Bucknell and others attempted the artificial process. James Canteto was more successful, and gave the subject considerable study. The theories that he put forward at that time, though based on no definite data, have been used as a basis for the construction of the various incubators to the present time.

Messrs. Jacob and Henry Graves of Reading and

Boston, Mass., were among the pioneers of this line of invention in this country (1870), followed closely by H. J. Haight of New York City, and Messrs. Woodward and Millet of Charlestown, Mass., in 1871. It is most remarkable that, though the various modifications of the incubator came thick and fast from 1875, none of the inventors have considered it of enough importance to investigate the old and formulate new principles based on reliable data, interpreted by the aid of the known laws of physics, a popular knowledge of which has increased rapidly during the last half century. There has been sufficient time and money expended in perfecting various machines for incubating purposes, but the workers in this line have been groping their way in the dark, and in consequence many of the contrivances which have encumbered the patent list have been based on no principle, justified by no proof, while some, even, are in direct opposition to the laws of nature. They were not familiar with nature's laws and consequently could not interpret the observed facts of natural incubation, and therefore were not masters of the fundamental principles upon which the success of their invention depended. Upon a knowledge of these laws depends the whole question of right and wrong, of success or failure.

We are confidently told by the enthusiastic poultry litterateur to go to Nature, that she never errs, etc. 'Tis true that Nature does not err, but human nature is very apt to. We would gain little knowledge of the laws that govern the incubation of an egg from watching a sitting hen for a lifetime, if we have no knowledge of the forces of nature at work, gathered from a close familiarity with the laws that govern analogous phenomena. If we know nothing of gold mining, or of the formations in which gold is found, or the methods for extracting it from the soil, we may dig in rich gold-bearing earth for months, and cart it off to fill in sunken lots. ○

There is a great difference between that knowledge

which is purely intellectual and that which is called natural knowledge. "A clever man, shut up alone and allowed unlimited time, might reason out for himself all the truths of mathematics by proceeding from those simple notions of space and number of which he cannot divest himself without ceasing to think, but he could never tell by any effort of reasoning what would become of a lump of sugar if immersed in water, or what impression would be produced on the eye by mixing the colors yellow and blue." The late Prof. Cooke, in one of his popular lectures, says: "In practical science the student is taught to follow out a chain of probable evidence, with care and caution to eliminate all accidental phenomena, and supply by experiment and observation the missing links, until he reaches the final conclusion, an intellectual process which, though based wholly on probable evidence, may have all the force and certainty of a mathematical demonstration. Indeed, that highly valued scientific acumen and skill which enables the student to brush away the accidental circumstances by which the laws of nature are always concealed until the truth stands out in bold relief, is but a higher phase of the same talent which marks professional skill in all the higher walks of life. The physician who looks through the external symptoms of his patient to the real disease which lurks beneath; the lawyer who disentangles a mass of conflicting testimony and follows out the truth successfully to the end; the statesman who sees beneath the froth of political life the great fundamental principles which will inevitably rule the conduct of the State, and thus foresees and provides for the coming change; the general who discovers amid the confusion of the battle-field the weak point of his enemy's front, and the merchant, even, who can interpret the signs of the unsettled market, employ the same faculty, and in not a much lower degree, that discovered the law of gravitation, and which, since the days of Newton, has worked so successfully to unveil the mysteries of the material creation."

CHAPTER II.

NATURAL INCUBATION.

IN order to understand the requirements of artificial incubation we shall need to first consider the observed facts in relation to the natural processes, by a comparison of which the general principles common to all may be deduced.

If left to herself a hen will prepare a shallow receptacle for the eggs, to aggregate them in a space that may be covered by the incubating body and keep in the warmth.

When a hen becomes broody after laying a clutch of eggs the plexus of the organ of incubation is developed, which consists of an arterial plexus ramifying beneath the integument of the abdomen, and form, by their unions, a rich network of vessels which becomes truly extraordinary in the time of hatching. Thus the warm blood is brought to the surface which is opposite the eggs, bringing the latter to a temperature that approaches more nearly to that of the blood of the fowl than they would otherwise be brought.

After this preparatory stage a hen sits on the eggs more or less constantly for about twenty days, from time to time moving them about in the nest, probably adjusting them to her own comfort.

As a rule the larger number of a sitting of eggs will become arranged in a circle, with the broad ends forming the circumference. This seems to be due to the hen's turning or shifting her position on the eggs, and to the shape of the body of the hen and of the egg itself. During the latter stages of incubation the broad end becomes very slightly elevated, which is due in part to the nest becoming more hollow, and to the bulk of the contents of the egg being situated in the small end, making that portion of it the heaviest.

* In settling on the nest the hen makes a slight movement with the body from side to side which partially separates

the eggs and forces them out in the feathers, only a comparatively small surface of each egg coming in contact with the incubating body. Over a greater part of that portion of the egg opposite the hen's body a layer of down and feathers intervenes, which also covers in the outer end and the remaining portion of the surface. Many times the feathers on the abdomen either fall or are plucked off during incubation, and the eggs are then brought into direct contact with the warm body.

The number of times the hen will leave her nest, as well as the period of remaining away from it, varies with different hens, and the state of the weather. In very warm weather the hen often rises in the nest and throws her feathers out to cool her body, thus partially uncovering the eggs. If the weather be excessively warm during the latter stages of incubation the chicks will often be found dead in the shell.

For a few hours before first breaking the shell the labored breathing of the chicks can be heard, with an occasional pip and chirp, and the eggs sweat. After exclusion the chicks at first sweat profusely, are highly sensitive to the slightest current of air, and huddle close to the hen's body for warmth.

In tropical climates the heat of the sun is supposed in some instances to be sufficient for incubation, as the ostrich is said to leave her eggs to be hatched by the heat of the sun's rays alone when she breeds in the neighborhood of the equator, but to sit upon them if inhabiting a more variable climate. Sir Richard Owen says, however, that "A steady continuous temperature of about 100 Fahr. is the requisite condition of successful incubation: the heat of the sun alternating with the cold of night would hatch no bird's egg. The ostrich deposits about fifteen eggs in a hollow of the sand, the male bird incubates, and the young are excluded in from fifty to sixty days." (American Ostrich, male incubating, 35 days.)

The nesting habits of one of our wild ducks, variously known as the Piled-billed Grebe, Little Dipper, or Fish Duck, are of interest, the following notes of which are

given by Langdon in his list "Summer Birds of a Northern Ohio Marsh" :—

"The little floating island of decaying vegetation held together by mud and moss, which constitutes the nest of this species, is a veritable ornithological curiosity. Imagine a 'pancake' of what appears to be mud, measuring twelve or fifteen inches in diameter, and rising two or three inches above the water, which may be from one to three feet in depth; anchor it to the bottom with a few concealed blades of 'saw-grass,' in a little open bay, leaving its circumference entirely free; remove a mass of wet muck from its rounded top and you expose seven or eight soiled brownish-white eggs, resting in a depression the bottom of which is less than an inch from the water: the whole mass is constantly damp. This is the nest of the Dabchick, who is out foraging in the marsh, or perhaps is anxiously watching us from some safe corner nearby. The anchoring blades of coarse saw-grass or flags, being always longer than is necessary to reach the bottom, permit of considerable lateral and vertical movement of the nest, and effectually provide against drowning of the eggs by any ordinary rise in the water-level such as frequently occurs during the prevalence of strong easterly winds on the lake. A small bunch of saw-grass already growing in a suitable situation is evidently selected as a nucleus for the nest, and the tops bent so as to form part of it.

"During the day we invariably found the eggs concealed by a covering of muck as above described; but as we ascertained by repeated visits at night and in the early morning they are uncovered at dusk by the bird who incubates until the morning sun relieves her of her task."

The following remarks relating to the breeding habits of the Black Tern, are also given in the same work :—

"A very common summer resident in the marsh, nesting, or rather laying its eggs on the islands of decaying vegetation and mud formed by sunken muskrat holes. Three eggs constitute a full set, and they are apparently

rolled about in the mud until well coated, so as to hide the markings and thereby make them less conspicuous. In two or three instances only did we observe any attempt at a nest, and these would not have been recognized as such without the eggs, consisting as they did of merely a few fragments of grass or bulrushes so disposed as to prevent the eggs from rolling; in most cases the eggs rested in a slight depression on the bare mud. The sun appears to be their chief incubator, although the decaying vegetation, of which the abandoned muskrat houses consist, doubtless plays some part in the process. In no instance did we succeed in flushing a bird from the eggs, although they would appear in pairs to the number of twenty or thirty, and hover about within a few feet of our heads making a great outcry when we approached their property, which was soon to be ours by right of discovery."

The most striking exception to the rule of incubation is given by the Megapodes or mound-birds, whose range extends from the Phillipines through the islands of the Indian Archipelago and Australasia. A huge mound of decaying vegetable matter is raised, the eggs are deposited vertically in a circle at a certain depth, and the chick is developed with the aid of the heat of fermentation. The egg is of large size, which affords a supply of material sufficing for a unusually advanced state of development of the chick at exclusion, whereby it has strength to force its way to the surface of the hatching mound, with wings and feathers sufficiently developed to enable it to take a flight to the nearest branch of an over-shadowing tree.

There are upwards of thirty species of the family Megapodidæ, all of which have the peculiarity of burying their eggs in heaps of soil and decaying vegetable substances, trusting to the heat engendered by the decomposing mass for incubation. The mounds differ very much in their composition and form according to location and species of bird. They vary in size from fifteen feet to 175 feet in circumference, the latter usually

being found in the densest thickets, and are doubtless the work of many ages, and of many birds in succession. In the smaller mounds the eggs are deposited so as to form a circle directly in the centre of the mound, at about two feet in depth, separated only by about three inches of earth. In the larger ones but a single egg is laid in each hole, at a depth of from five to seven feet, and after the egg is deposited the earth is immediately thrown down lightly until the hole is filled up.

CHAPTER III.

THE EMBRYONIC DEVELOPMENT OF THE CHICK.

It will be found essential to a comprehensive understanding of the Phenomenon of Incubation to have a general knowledge of the Embryonic Development of the Chick.*

THE STRUCTURE OF THE EGG.

In a fresh egg the following structures are met with:—

The most external is the *shell*, composed of calcareous matter, the particles of which are deposited in a regular manner, designed to give strength and porosity.

It consists of an outer thinner and an inner thicker layer, both of which are pierced by vertical canals, opening freely on both the exterior and interior surfaces. Through these canals the interchange of gases between the interior and exterior air takes place, and the chemical process of respiration, though feeble at first, gradually increases in intensity, and is thus carried on during the whole period of incubation.

The appearance to the unaided eye of pores on the surface of the shell is due to the impressions of the villi of the formative membrane, the permeability of the shell by the atmosphere depending on a more minutely porous texture. The first effect of this porosity is the penetration of air between the layers of the lining membrane as

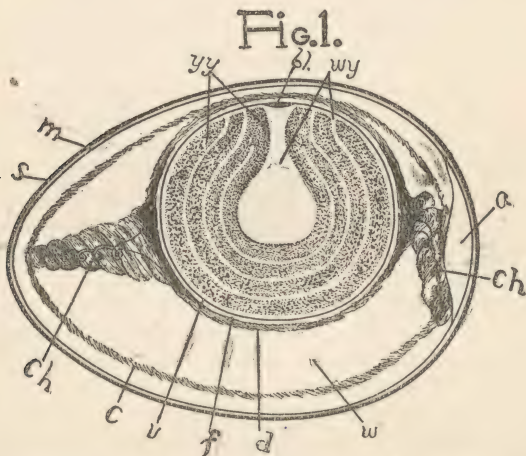
*I am indebted for the substance of this chapter to Foster & Balfour's "Elements of Embryology," to which valuable work the reader is referred for a more minute description than is here given. I only give here the most important facts—those that we shall need to know in discussing the phenomenon of incubation; generalizing where details would only confuse the casual reader, and making such corrections as later observations seem to warrant.

I claim as my own observations the facts relating to the disappearance of the amniotic fluid, and the chick's then breathing the air contained in the amniotic sac, whereby the pulmonary circulation becomes functionally active before the rupture of the covering membranes.

Figures three and four are from the same work, while one and two are modifications of others. Figures five and six are my own. They give a very good idea of the positions of the chick and other contents of the egg at eleven and sixteen days.

the contents of the egg condense by cold and evaporation after it is laid. The air accumulates at the large end of the egg, between the two membranes, and increases in quantity as the other contents become condensed into the tissues of the chick, and contains a larger per cent. of oxygen than ordinary atmospheric air.

The air space appears as the egg condenses on cooling, and gradually increases in size, whether the egg is incubated or not, as the albumen, which contains 78 per cent. of water in its composition, shrinks in bulk by evaporation.



Diagrammatic section of an unincubated fowl's egg, *bl*, blastoderm, or germ-spot; *wy*, white yolk, consisting of a central flask-shaped mass, and a number of layers concentrically arranged around it, the outer layer of white yolk lying immediately beneath the vitelline membrane, and connected with the central mass beneath the blastoderm; *yy*, yellow yolk; *v*, vitelline membrane; *f*, layer of more fluid albumen surrounding the yolk; *ch*, chalaze; *a*, air chamber between the two layers of the shell membrane; *m*, shell membranes, where they lie in contact over the greater portion of the egg; *s*, shell; *d*, denser albumen, which extends around the yolk outside of the internal layer of more fluid albumen; *c*, boundary between the outer and middle portion of the albumen.

Lining the shell is the *shell membrane*, which is double, there being an outer thicker and an inner thinner one.

Over the greater part of the egg the two layers of the shell membrane remain permanently in contact (*m*); but at the broad end they tend to separate, and thus to develop between them a space into which air accumulates (*a*).

Beneath the shell membrane is the *white* of the egg, consisting of alternate layers of denser and more fluid *albumen*, the average composition of which may be taken as 20.40 per cent. proteid matter; 1.60 per cent. saline matter, chiefly sodic and potassic chlorides, with phosphates and sulphates; and 78.00 per cent. water.

In a hardened egg a spiral arrangement of the white may be observed, and it is possible to tear off thin layers in a spiral direction from left to right from the broad to the narrow end of the egg.

Two twisted cords, termed the *Chalaze* (*ch*), composed of coiled membranous layers of dense albumen, run from the two extremities of the egg to the opposite portions of the yolk. Their inner extremities expand and merge into the layer of denser albumen (*d*) surrounding the fluid layer (*f*) next the yolk. The outer extremities are free, and do not quite reach the outer layer of the white. The function of the chalaze is to keep the yolk more steady in the albumen, and to moderate the effects of any violent movement or rotation of the egg. The interior of each chalaze presents the appearance of a succession of opaque white knots.

The yolk is enclosed in the *vitelline membrane* (*v*), a transparent and almost structureless membrane, devoid of pores. It is somewhat elastic, and easily thrown into creases and wrinkles.

On the upper surface of the yolk, and immediately under the vitelline membrane will be seen a little semi-opaque spot about one-eighth of an inch in diameter. This is the *blastoderm* or *germ-spot* (*bl*).

The blastoderm of a fertile egg will show an outer white rim, and within that a circular transparent area, in the centre of which, again, there is an opacity, sometimes uniform, and sometimes dotted. In an unfertile egg this

white disc is simply marked with a number of irregular clear spaces, there being no proper division into a transparent centre and an opaque rim. This spot in the unfertile egg has sometimes been looked upon as a scar left where the yolk broke from its cell or capsule.

During the descent of the egg along the oviduct of the fowl, where it is exposed to a temperature of 110 degrees or more, the blastoderm undergoes important changes. When the egg is laid and becomes cold, the changes all but entirely cease, and the blastoderm remains inactive until, under the influence of the higher temperature of natural or artificial incubation, the vital activities of the germ are brought back into play, and the arrested changes go on again. The condition of the blastoderm at the time when the egg is laid is not exactly the same in all eggs, though the differences of course are slight. In warm weather changes of the same kind as those caused by actual incubation may take place, to a certain extent, in the interval between laying and incubation.

The blastoderm is always found to be uppermost, whatever may be the position of the egg, provided there is no restraint to the rotation of the yolk. The explanation of this is to be sought for in the lesser specific gravity of that portion of the yolk which is in the neighborhood of the blastoderm. Though to the naked eye the yolk appears tolerably uniform throughout, a section of the yolk of a hardened egg will show that it is not perfectly uniform, but that there is a portion of it having the form of a flask (*wy*) with a funnel-shaped neck and a number of layers concentrically arranged around it; which, when the egg is boiled, does not become so solid as the rest of the yolk, but remains more or less fluid. The expanded neck of this flask-shaped space is situated immediately underneath, and where it forms a bed on which the blastoderm (*bl*) rests; while its bulbous enlargement is about the middle of the yolk. This is known as the *white yolk* (*wy*), while the great mass of the yolk is composed of what is known as the *yellow yolk* (*yy*).

The yolk as a whole is of a lesser specific gravity than

the albumen, in which it is immersed, while the pressure of the up-floated germ against the shell-wall is moderated by the weight of the denser albumen forming the chalaze.

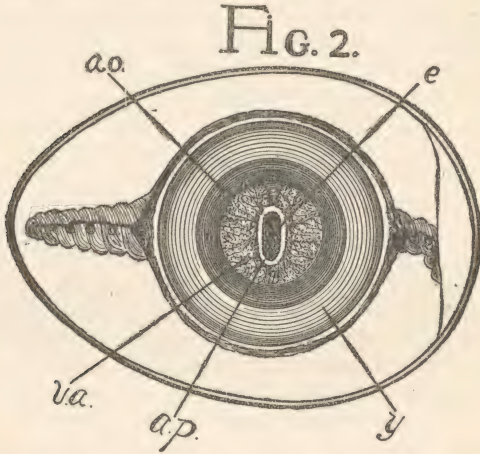
The attachments of the chalaze being a little below the axis of the yolk, it adds its weight to the lower half, and thus helps to make the germinal half the lightest and uppermost. Under ordinary circumstances rotation of the egg takes place on its long axis, and if a fresh egg be turned round, the blastoderm will keep its position upwards for one turn or a little more, and then, by the twisting of the chalaze, the yolk is carried completely round, and balances itself again with the blastoderm uppermost in its new position. These modifications of the oviparous egg, so delicately wrought, so wondrously endowed, in anticipatory relation to the needs and conditions of incubation, are scarcely conceivable.

THE BLASTODERMIC EXPANSION.

In the fertile blastoderm, as above noted, the naked eye can distinguish an opaque rim of some breadth surrounding a more transparent central area, in the middle of which again is a white spot of variable appearance. The opaque rim is the commencement of what is termed the *area opaca*; the central transparent portion is in the same way the beginning of the *area pellucida*.

The blastoderm which at first lies with its margin resting on the circular wall of flask-shaped white yolk, spreads out, as a thin circular sheet, over the yolk, immediately under the vitelline membrane. Increasing uniformly at all points of its circumference, the blastodermic expansion covers more and more of the yolk, and at last reaching its opposite pole, completely envelops it. Thus the whole yolk, instead of being enclosed as formerly by the vitelline membrane alone, comes to be also enclosed in a bag formed by the blastoderm, termed the *germinal membrane*. It is not, however, until quite a late period that the complete closing in at the opposite pole takes place, so that the extension of the blastoderm,

or germinal membrane, must be considered as going on during nearly the whole period of incubation. Both the area opaca and the area pellucida share in this enlargement, but the area opaca (Fig. 2, *ao*) increases much more rapidly than the area pellucida (*ap*), and plays the principal part in encompassing the yolk.



A fowl's egg after about forty-eight hours incubation, viewed from above, the upper portion of the shell being removed: *y*, yolk; *ao*, area opaca, or that portion of the blastoderm which extends over the yolk as the germinal membrane; *va*, the vascula area of the area opaca, the growth of which is somewhat slower than the germinal membrane; *ap*, area pellucida, in the centre of which lies the embryo, *e*.

The circular transparent area, or that part of the area opaca which is nearest the area pellucida, becomes the seat of peculiar changes, which result in the formation of blood-vessels. Hence this part of the area opaca is called the *vascula area* (*va*). The embryo (*e*) itself grows out from the most central portion of the blastoderm, or the central portion of the area pellucida (*ap*). The head appears first, and several hours later the tail, when the embryo has the appearance of being encased in a small sac and lying in a depression of the yolk-sac, with which it is connected. As incubation proceeds the embryo

gets larger at the expense of the yolk, which is gradually assimilated by nutritive processes.

Within a day or two of the hatching of the chick, at a time when the yolk-sac is still of some size, or at least has not yet dwindled away altogether, and the development of the embryo is nearly complete, the yolk-sac is slipped into the body of the embryo, so that ultimately the embryo with its coverings alone remain.

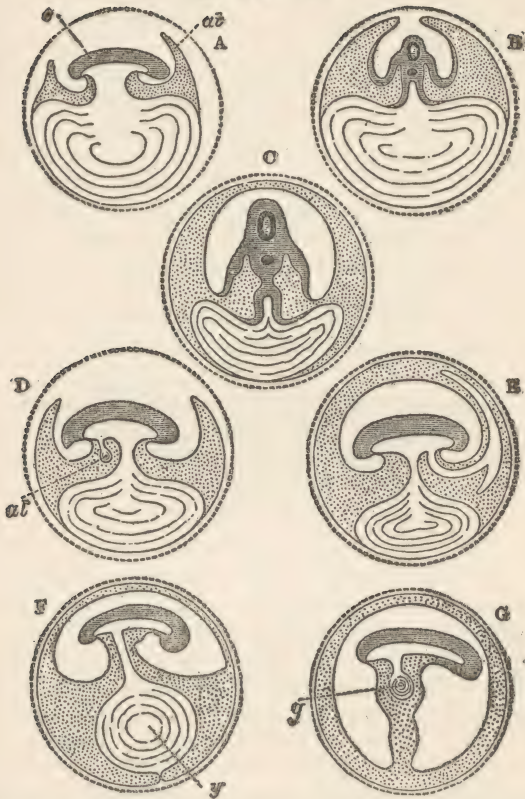
The general shape of the embryo is due to the direction and slope of the several outgrowths which share in its formation. In addition to this, the tubular sac of the embryo, while everywhere gradually acquiring thicker and thicker walls, undergoes at various points, through local activities of growth in the form of thickenings, ridges, buds or other processes, many modifications of the original outline conferred upon it. Thus, bud-like processes start out from the trunk to form the rudiments of the limbs, and similar thickenings and ridges give rise to the jaws and other parts of the face. By the unequal development of these outgrowths the body of the chick is gradually moulded into its proper outward shape. At the same time other growths take place within the body walls of the embryo, which result in the formation of the heart, liver, lungs, etc.

THE AMNION.

Very closely connected with the appearance of the head of the embryo is the formation of the *amnion*.

The amnion is developed in the following way: There first appears, a little way in front of the head, a fold or thin outgrowth running around in front of it (*at*). As it increases in height it is gradually drawn backwards over the developing head of the embryo (*e*). The fold thus covering the head is in due time accompanied by similar folds at some little distance behind the tail, and at some little distance from the sides (*B*). In this way the embryo becomes surrounded by a series of folds of thin membrane, which form a continuous wall all around it. All are drawn gradually over the body of the embryo,

Fig. 3.



DIAGRAMS ILLUSTRATING THE DEVELOPMENT OF THE AMNION AND ALLANTOIS.

In *A* the embryo (*e*) is seen lying in a depression on the yolk-sac, the folds of the amnion are rising up at either end of the embryo, the fold in front of the head (*at*) being the larger. In *B* the amniotic folds nearly meet, and in *C* they have entirely coalesced. In *D*, which is a little later stage than *A*, the allantois (*al*) is seen budding out from the intestine. In *E*, which is a stage corresponding with *C*, the allantois is seen extending round the embryo. In *F*, the yolk-sac (*y*) is reduced in size, and in *G* it is being withdrawn into the body of the embryo. The allantois in *F* and *G* is omitted for the sake of simplicity. These diagrams only very roughly indicate the relations of the parts.

and at last meet and completely coalesce (*C*), all trace of their junction being removed. Beneath these united folds there is therefore a concavity or sac within which the embryo lies.

When the several folds meet and coalesce together above the embryo, they unite in such a way that all their inner surface goes to form a continuous inner membrane or sac, and all their outer surface a similar continuous outer membrane or sac. The inner membrane thus built up forms a complete closed sac around the body of the embryo, and is called the *amniotic sac*, or *Amnion proper* (Fig. 5, *am*), and the fluid which it afterwards contains is called the *amniotic fluid*, or *liquor amnii*. The outer sac over the embryo lies immediately beneath the shell membrane, where it forms the outermost of the embryonic appendages, or *chorion*.

If the mode of origin of these two sacs, the inner or true amnion, and the outer or false amnion, and their relations to the embryo be borne in mind, the reader will have no difficulty in understanding the course taken in the growth of a very important organ, the *Allantois*.

THE ALLANTOIS.

The allantois is fundamentally an appendage of the alimentary canal, and is thrown out at the hinder end of the embryo (*D, al*). It very rapidly pushes its way, by the development of a long tube, into, and fills the space developed between the true and false amniotic sacs, and with the latter it extends over the yolk and albumen (Fig. 3, *E*, and Fig. 5, *al*), separated from the shell membranes by nothing more than the thin false amnion; and in this position it performs its function as a respiratory organ, or lungs.

FIRST DAY.

During the first twelve hours of incubation the blastoderm when viewed from above is found to have increased greatly in size. The central white spot, or pellucid area, which at the best is but obscurely marked in the unincubated egg becomes oval in outline, and very distinct, and

contrasts strongly with the outer opaque rim, which has been still more increased, both in distinctness and size.

During the latter part of the first day is seen the first definite appearance of the head, and the first trace of the amnion appears in front of it. The vascular area also begins to be distinguished from the rest of the blastoderm.

SECOND DAY.

At the beginning of the second day the head alone projected above the rest of the germ, the remainder of the embryo being simply a part of a flat blastoderm. At about the twenty-sixth hour the tail makes its appearance, being elevated above the level of the blastoderm in the same way that the head was elevated.

The amnion, especially the anterior or head-fold, advances in growth very rapidly during the second day, and at its close completely covers the head and neck of the embryo. The tail and side folds of the amnion, though still progressing, lag considerably behind the head-fold.

The first rudiment of the heart appears about the twenty-seventh hour, and is of a tubular character, being formed by a longitudinal fold of the vascular layer. For some time it is undivided, being simply a long tube extending through nearly the whole length of the embryo. Although the development has proceeded thus far at about the thirty-fifth hour, no motion is seen in the heart or vessels until the thirty-eighth or fortieth hour.

When the heart first begins to pulsate it contains only colorless fluid mixed with a few globules. A movement of the dark blood in the circumference of the vascular area is at the same time perceived, but it is independent of the constrictions of the heart, and it is not until a subsequent period that a communication is established between the heart and the distant vessels, and the dark fluid contained in them arrives at the central cavity and is propelled by its pulsations. The formation of fluid goes on in every part of the body, and, when formed, it is put in motion by some unknown cause that impels it into the proper direction, until at length it reaches the central

formation of fluid, around which is developed a tubular canal afterwards to be modified and changed into a heart. The first movements of the blood are towards the heart, and consequently the first vesicles formed are veins.

The blood-vessels which are first observed in the body of the embryo as well as in the vascular area appear formed in insulated points, which gradually coalesce so as to form tubes. No difference is at first observed between the characters of the arteries and those of the veins, and they are only to be distinguished by the direction of the currents of blood circulating through them. Subsequently, however (about the fourth or fifth day of incubation), the coats of the arteries begin to appear thicker than those of the veins, and the distinction between them soon becomes evident.

Between the fortieth and fiftieth hours a separation of the heart in parts may be observed, which is effected by a constriction around the middle of the tube and the dilation of the posterior into a ventricular cavity.

THIRD DAY.

Between the fiftieth and sixtieth hours the circulation of blood in the vascular area becomes more vigorous; the tube of the heart becomes more and more bent together until it is doubled, so that this organ now becomes much shorter relatively to the dimensions of the body, and is more confined to the portion of the trunk to which it is subsequently restricted.

The blood-vessels become during the latter part of the second day connected so as to form a complete system, through which a definite circulation of blood is for the first time (consequently some little while after the commencement of the heart's pulsations) carried on.

Nutritive matter is transmitted to the blood by the under surface of the vascular area, and by the blood conveyed to all regions of the body of the embryo, the yolk in contact with it losing its coagulability. As the yolk is absorbed, it is in turn replenished at the expense of the white. The absorption, once begun, goes on so

actively that by the end of the third day the decrease of the white is very striking.

The blastoderm is now spread over about half the yolk, the extreme margin of the germinal membrane reaching about half way towards the pole of the yolk opposite to the embryo. The vascular area, although still increasing in size, is much smaller than the outer opaque area, being in average sized eggs about as large as a quarter. Still smaller than the vascular area is the pellucid area, in the centre of which lies the rapidly growing embryo.

During the third day the vascular area is not only a means for providing the embryo with nourishment from the yolk, but also insomuch as by the diminution of the white it is brought close under the shell, and, therefore, fully exposed to the influence of the atmosphere, serves as the chief organ of respiration.

The embryo is almost completely covered by the amnion. At the close of the day the several amniotic folds will have met along a line over the back of the embryo. Their complete coalescence and the obliteration of their line of junction will, however, not take place until the following day.

During the third day a most remarkable change takes place in the position of the embryo. Up to this time it has been lying symmetrically upon the yolk with the part which will be its mouth directed downwards. (If an egg be placed with its broad end to the right of the observer, the head of the embryo will in nearly all cases be found pointing away from him. Duval found 163 out of 166 examined, in this position.) It now turns around so as to lie on its left side. This remarkable change of its position is almost invariably completed on the third day. Coincidentally with the change of position the whole embryo begins to be curved on itself. This curvature of the body becomes still more marked on the fourth day.

FOURTH DAY.

On opening an egg in the middle or towards the end of the fourth day a number of points in which progress has

Fig. 4.

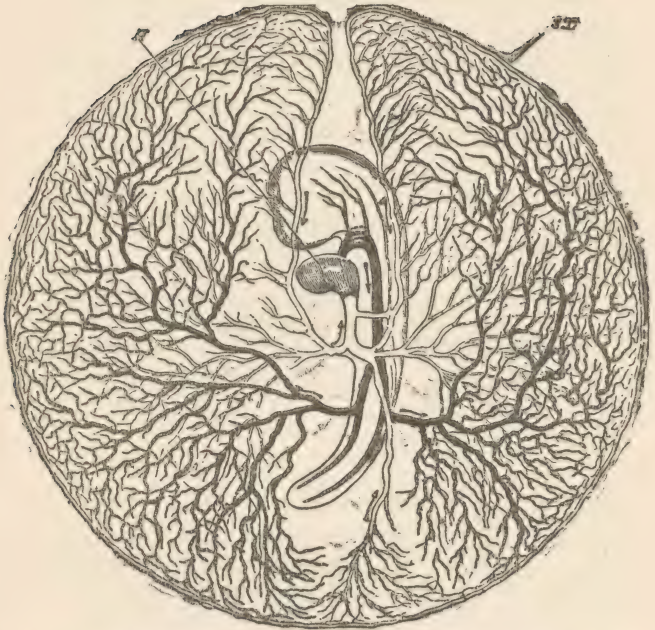


Diagram of the circulation of the yolk-sac (vascular area), at the end of the third day of incubation. The veins are marked in outline, and the arteries are black. The whole blastoderm has been removed from the egg, and is supposed to be viewed from below, hence the apparent reversal of the sides. *H* is the heart, and *S T* sinus terminalis — the vein which brings the blood back to the heart.

been made since the third day are at once apparent. In the first place, the growth of the embryo has been very rapid, so that its size is very much greater than on the previous day. In the second place, the white of the egg is still further diminished, the embryo lying almost in immediate contact with the shell membrane. The germinal membrane embraces more than half the yolk, and the vascular area is about as large as a half-dollar.

Corresponding to the increased size of the embryo there is a great increase in the activity of the blood circulating in the vascular area.

The amnion becomes increasingly conspicuous. It is now seen as a distinct covering, obscuring to a certain extent the view of the body of the chick beneath, and all trace of the junction of its folds are by this time lost. As yet there is very little fluid in the amniotic sac proper, so that the dry amnion lies close upon the embryo.

The tail, which commences to be noticeable during the third day is during this day increased very much, and the somewhat curved tail forms quite a conspicuous feature of the embryo.

The general curvature of the body is also increasing, and as the result of these various flexures the embryo has very much the appearance of being curved upon itself.

The distinct appearance of the limbs must be reckoned as one of the most important events of the fourth day.

The allantois becomes for the first time conspicuous on this day, though the first appearance of the rudiments of it appear on the third. Soon after its appearance the allantois may be easily recognized as a pear-shaped vesicle, connected with the under surface of the alimentary canal by a long hollow stalk. It does not during the third day project beyond the body of the chick, but on the fourth day begins to pass out on its way to that space between the external and internal folds of the amnion. In this space it spreads out and eventually encloses the whole contents of the egg beneath the shell membrane (Fig. 6, *a*). On the first half of the day it is very small, and its growth is not very rapid. In the latter half of the day its growth becomes more rapid, and it forms a very conspicuous object in a chick of that date. At the same time its blood-vessels become important.

FIFTH DAY TO END OF INCUBATION.

On opening an egg about the middle of the fifth day the observer's attention is not arrested by any new feat-

ures, but he notices that the progress of development, which was so rapid during the latter half of the fourth day, is being continued with undiminished vigor. The allantois, which on the fourth day began to project from beneath the embryo, has grown very rapidly, and now stretches far over the right side of the embryo (which it will be remembered is lying on its left side) in the cavity between the two amniotic folds. It is very vascular, and already serves as the chief organ of respiration.

The germinal membrane has spread over the whole of the yolk sac, and the yolk is thus completely enclosed in a bag whose walls, however, are excessively delicate and easily torn. The vascular area extends over about two thirds of the yolk. The embryo remains excessively curved, so much so, indeed, that the head and tail are nearly in contact.

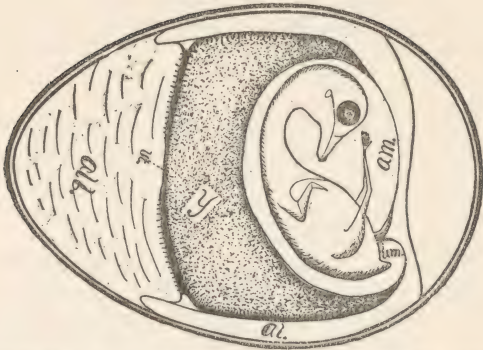
The amnion at its complete closure on the fourth day very closely invested the body of the chick, the true cavity of the amnion was then therefore very small. On the fifth day fluid begins to collect in the cavity, and raises the membrane of the amnion to some distance from the embryo. The cavity becomes still larger by the sixth day, and on the seventh day it is of very considerable dimensions, the fluid increasing in it.

By the seventh day very obvious movements begin to appear in the amnion, its slow vermicular contractions creep rhythmically over it. The amnion, in fact, begins to pulsate slowly and rhythmically, and by its pulsation the embryo is rocked to and fro in the egg. Similar movements are also seen in the allantois at a considerable later period.

The growth of the allantois has been very rapid, and it forms a flattened bag covering the right side of the embryo, and rapidly spreading out in the direction between the primitive folds of the amnion, that is between the amnion proper and the false amnion, or chorion. It is filled with fluid, so that in spite of its flattened form its opposite walls are distinctly separated from each other.

The vascular area has become still further extended

FIG. 5.



A diagrammatic section through the fowl's egg about eleven days incubated. *Al*, cavity of the allantois; *alb*, albumen; *am*, cavity of the amnion; *um*, umbilicus, or small hollow tube connecting the embryo with the amnion, yolk-sac and allantois. The outer covering of the umbilicus is formed by the amnion, and is continuous with the body wall of the embryo. Through this tube passes that of the allantois, and also that of the yolk-sac. By means of the latter the walls of the alimentary canal are continuous with the membrane covering the yolk-sac, and the interior of the canal is continuous with the inside of the yolk-sac. At a comparatively early period the canal of this stalk becomes obliterated, so that the material of the yolk can no longer pass directly into the alimentary cavity, but has to find its way into the body of the chick by absorption through the blood-vessels.

When in the last days of incubation the greatly diminished yolk-sac with its germinal investment is withdrawn into the rapidly enlarging abdominal cavity of the embryo, the walls of the abdomen close in and unite without any regard to the amnion and the shriveled, emptied allantoic investment, which are cast off as no longer of any use.

than on the previous day, but with a corresponding loss in the definite character of its blood-vessels. The sinus terminalis (thin red line around the extreme margin of the vascular area, and nearly completely encircling it) has, indeed, by the end of the seventh day lost all of its previous distinctness, and the vessels which brought back the blood from it to the heart are no longer to be seen. The yolk is not so fluid as on the sixth day, though it continues to absorb the white of the egg, which is diminishing rapidly. The liquid thus absorbed by the yolk from the albumen serves for the formation of the amniotic and allantoic fluids.

During the eighth, ninth and tenth days the amnion does not undergo any very important changes. Its cavity is still filled with fluid, and on the eighth day its pulsations are at their height, henceforward diminishing in intensity.

The allantois now spreads out over the greater part of the yolk-sac as a flattened bag filled with fluid, and serves as the chief organ of respiration. Hence it is very vascular, the vessels on the right side of the bag, which is turned to the chorion and shell, being especially large and numerous.

The yolk now begins to diminish rapidly in bulk. The yolk-sac becomes flaccid, and, on the eleventh day, is thrown into a series of internal folds abundantly supplied with blood-vessels. By this means the surface of absorption is largely increased, and the yolk is more and more rapidly taken up by the blood-vessels, and in a partially assimilated condition transferred to the body of the embryo.

By the eleventh day the abdominal walls, though still looser and less formed than the walls of the chest, may be said to be definitely established, and the loops of intestine, which have hitherto been hanging down, are drawn up into the abdomen. The body of the embryo is therefore completed, but it still remains connected with its various appendages by a narrow umbilicus (Fig. 5, *um*) in which run the stalk of the allantois and the solid cord suspending the yolk-sac. The allantois still growing rapidly, it completely surrounds the whole contents of the egg, except at the pole opposite to the embryo, where for some little time a small portion of albumen remains unenclosed; at this spot the diminished white of the egg adheres as a dense viscid plug.

The allantois lies over the embryo, close under the shell, being separated from the shell membrane by nothing more than a thin membrane formed out of the outer primitive fold of the amnion, and the remains of the vitelline membrane. With this membrane the allantois partially coalesces, and in opening an egg at the latter stage of

incubation, unless care be taken, the allantois is in danger of being torn in the removal of the shell membrane.

On about the sixteenth day the allantois is carried right over the poll of the yolk opposite the embryo, and is thus completed.

FIG. 6.



A diagrammatic section through a fowl's egg about sixteen days incubated; *al*, cavity of the allantois. The allantois now completely envelops the embryonic and yolk-sacs, and the remaining portion of albumen, *alb*. The amnion, *am*, is losing fluid, and very closely envelops the embryo, while the yolk, *y*, is seen folded over it. The allantois becomes thinner and thinner as incubation progresses, so that at the last its two walls lie in direct contact, the fluid and cavity entirely disappearing.

Deposits of urates now become abundant in the allantoic fluid. The loose and flaccid walls of the abdomen enclose the space which the empty intestines are far from filling, and on the nineteenth day the yolk-sac, diminished greatly in bulk, is withdrawn through the umbilicus into the abdominal cavity which it largely distends. Outside the embryo there remains nothing now but the highly vascular allantois and the practically fluidless amnion.

By the sixth or seventh day the flexure of the body has become less marked, so that the head does not lie so near to the tail as on the previous days, and the same time a more distinct neck makes its appearance. Though the

head is still disproportionately large, its growth ceases to be greater than that of the body.

So early as the ninth or tenth day the sacs containing the feathers begin to protrude from the surface of the back as papillæ, especially prominent at first along the middle line of the back, from the neck to the rump and over the thighs, the sacs of the tail feathers being very conspicuous. On the thirteenth day these sacs, generally distributed over the body, and acquiring a length of a quarter of an inch or more, appear to the naked eye as feathers, the thin walls of the sacs allowing their contents, now colored according to the breed of the bird, to shine through. They are still, however, closed sacs, and indeed remain such even on the nineteenth day, when many of them are of a considerable length.

On the eighth day a chalky-looking patch is observable on the top of the nose. This, by the twelfth day, has become developed into a horny, but still soft, beak.

On the thirteenth day nails are visible at the extremities, and scales on the remaining portions of the toes. These on the sixteenth day become harder and more horny, as does also the beak.

By the thirteenth day the cartilaginous skeleton is completed, and the various muscles of the body can be made out with tolerable clearness.

Ossification begins on the eighth or ninth day. As early as the sixth day movements may be seen in the limbs of the embryo upon opening the egg. We may conclude from this fact that spontaneous movements occur from time to time in the unopened egg. They cannot, however, be of any great extent until the fourteenth day, for up to this time the embryo retains the position in which it is formed, viz., that with its body at right angles to the long axis of the egg.

On the fourteenth day a definite change of position takes place: the chick moves so as to lie lengthwise in the egg, with its head opposite the chorion and shell membrane where they form the inner wall of the rapidly increasing air-chamber at the broad end.

By the eighteenth day the fluid in the amniotic sac, in which the embryo lies, has entirely disappeared, and the chick is breathing the air which it contains. The pulmonary circulation, which has been gradually developing since the third day, increases in activity, and the circulation of blood in the allantois correspondingly diminishes.

By the twentieth day the fluid in the allantois has entirely disappeared, and the circulation of blood in the allantoic vesicles is quite sluggish. The chick now thrusts its beak through its coverings, and breathes the outer air. At this time the blood entirely ceases to flow through the umbilical arteries into the allantois, and the pulmonary respiration now becomes the sole means of its aeration. The allantois therefore dries up, and the umbilicus becomes completely closed. In from six to ten hours from the time of first breathing the outer air, the chick, breaking the shell around the broad end of the egg with rapid blows of its beak, casts off the dry remains of the amnion and allantois, and quits its primitive home.

CHAPTER IV.

HEAT.

IN all living beings, the taking in of food stuffs into the body, its conversion into a nutritious fluid, the blood, the elements of which supply the materials for the growth and renovation of the flesh, muscle, etc., and thus maintain their vital properties ; and the excretion, or throwing off of the particles unfit for these purposes, constitute the sum total of the vital acts by which the life of the individual is immediately supported.

All vital action, however, requires a certain amount of heat for its due performance, and can only continue within a particular range of temperature ; between the limits of which it is excited by the additional application of the stimulus, and depressed by its abstraction.

Thus it is seen that, for the normal exercise of the animal powers a steady temperature is necessary, and this is obtained by endowing the body itself with the means of generating warmth, and of resisting the violent action of external heat by refrigerating processes. By this means animals of the higher organization are rendered capable of enduring vicissitudes of temperature which would be fatal to many less perfect species, but the heat of its own body, which is that required for the continuance of its functions, varies extremely little.

Hence it is seen that the degree of external heat or cold cannot always be taken as an indication of that which is compatible with the performance of the actions of life, since if a warm-blooded animal in a temperate atmosphere is deprived of its power of generating heat it will speedily become incapable of continued existence, even at a degree of external heat which is fully sufficient for the energetic life of other organisms which are entirely dependent upon it.

ANIMAL TEMPERATURE.

Different species of animals exhibit great variations in the limitations of temperature which they require, and

in their power of adaptation to extreme conditions. The temperature of the human body is usually stated at 98 2-5 degrees, from the height of thermometers placed in the mouth, armpits, etc., but that of the stomach is generally 100, and that of the blood from 100 1-2 to 101 1-2.

The temperature of birds is somewhat higher than that of mammals, being from 100 to 111 1-4 degrees. The first is that of the gull and the last that of the swallow. The temperature of the common fowl is 110 (thermometer placed in the rectum), a chick a week old, taken from under a hen in the morning, will only have a temperature of about 106, while the temperature of a half-grown cock or duck often reaches 111 degrees.

GENERATION OF ANIMAL HEAT.

Animal or vital heat is generated by means of chemical changes going on in the process of respiration. When we breathe, air is taken into the lungs, penetrating the delicate vessels on their surface, the oxygen of the air enters the blood, and is carried by it, through the heart, to minute capillaries in the different organs. Here it unites chemically with the particles of carbon from the tissue, and heat is generated. Carbon dioxid, the new substance formed by the chemical action, is carried by the blood into the lungs to be exhaled, while a fresh supply of oxygen is obtained for a repetition of the process.

Heat is generated wherever oxidation takes place ; and hence, wherever food stuffs are being converted into the more highly oxidated products, heat is necessarily evolved. These processes are taking place in all parts of the body by which vital activity is manifested, and hence every bit of tissue, being traversed by capillary blood-vessels, is really a small fire-place in which heat is being evolved, in proportion to the activity of the chemical changes which are going on.

The production of heat from the actions of organic life depends on the amount of material for the support of such actions—on the quantity of oxidizable substance introduced as aliment into the body, and on the supply

of oxygen. Feeble and inactive young use up less oxygen proportionately than adults, and when exposed to cold, lose their heat and also their sensibility.

During the development of the chick within the egg the nutritive material needed for the growth of the blastoderm, and subsequently of the embryo, is supplied by the yolk, while oxygen of the air passing freely through the porous shell, gains access to all the tissues both of the embryo and yolk, either directly, or by the intervention of the allantoic vessels. From the very first oxidation is going on in the blastodermic structures, but the amount of oxygen actually withdrawn from without is probably exceedingly small in the early stages, as nearly the whole energy is directed to the building up of the structures, the expenditure of energy in the form of heat being extremely small.

REGULATION.

Heat is not only being constantly generated in, and distributed through, the body, but it is subject to incessant regulation. If there were no greater loss of heat than that given off to surrounding media by what we shall learn to know as conduction, radiation, and convection, the temperature of the animal body would soon rise to such a height, when the external temperature was great, as to interfere with its vital functions. This most important refrigerating process, which acts as a counter balance, or temperature regulator, is to be found in the varying, but constant, loss of moisture from the body. This loss of moisture is effected through the medium of the lungs and by the secretion of sweat from the surface of the body, which, being poured out of the perspiratory ducts in a fluid form, and carried off as vapor, by the atmosphere, necessarily renders latent a large quantity of heat energy, and thus diminishes the sensible heat of the exhaling body.

Or, in other words, the effect of the evaporation is to reduce the temperature of the evaporating surface. When water is converted into vapor, heat is consumed in over-

coming cohesion, or that force which binds the molecules of water together, and cold is produced, the heat being carried away with the vapor. Every drop of water which is converted into vapor carries away as much heat as would raise the temperature of a similar drop about five hundred degrees higher if it were not evaporated.

Evaporation takes place constantly from the surface of the animal body, and thus it assists powerfully in maintaining the equable temperature essential to health. Perspiration usually passes away at once as invisible watery vapor, but when it is profuse a part may remain for a time as a fluid on the skin; the former is spoken of as insensible, and the latter as sensible perspiration. Considerable watery vapor is also constantly being carried off by the breath exhaled, amounting to about two thirds as much as that thrown off by the whole surface of the body. This can be made perceptible to the eye by breathing against a pane of glass. It is also seen as a dense mist on a winter's day, caused by condensation on coming in contact with the cold air.

This powerful heat regulator enables the animal economy to resist very high temperatures when the external conditions are favorable to a quick evaporation of the exhaled fluid. Thus the oven girls of Germany, clad in thick socks of woolen, to protect the feet, enter ovens where all kinds of culinary operations are going on, at a temperature often above three hundred degrees, although the touch of any metallic article while there would severely burn them. Persons have been subjected for a considerable period in a dry air to a temperature of 210 degrees, without much inconvenience, while exposure to watery vapor of 125 degrees, or immersion in water of 113 degrees cannot be continued for many minutes.

HEAT A STIMULANT.

Heat is the immediate stimulus supplied by the hen to arouse the sleeping energy of the blastoderm to vital action, and it is upon this external source the embryo is dependent for the warmth necessary to its full develop-

ment. For the same reason we shall need to supply heat to the egg in artificial incubation, and in order to do it intelligently we shall need to know as much of heating by combustion as we have already learned regarding animal heat.

HEAT STORED UP IN THE VEGETABLE.

The sun is our great source of heat, whose rays alone make the earth inhabitable. All the combustible material on the earth would not supply the want of the sun for a single day. In fact, if we did not originally have the sun, we would have had no combustible material, as those materials are only stored up by heat energy derived from the sun. The elements—nitrogen, hydrogen, carbon, etc.—of the primary organic compounds, are drawn from the air and soil and metamorphosed into vegetation through the action of the sun. That is, the energy emitted from the sun, under the forms of heat and light, is capable, through the medium of the plant, of disengaging oxygen from its combination with carbon in carbon dioxide, and hydrogen in water, leading to the formation of re-oxidizable compounds; and the energy evolved from the re-oxidation of these compounds, whether by combustion in the air or within the animal system, represents or forms the equivalent of that employed in effecting their construction. Our coal-fields represent a vast magazine of force drawn ages ago from the sun's rays, which is capable at any moment of being set free by the occurrence of oxidation.

HEAT LIBERATED BY COMBUSTION.

The vegetable products are devoured by the animal, and through the chemical action taking place in the body, the force heat is liberated, which was originally absorbed from the sun, while the gases are set free. This force liberated in the animal system we call animal heat. If we burn the vegetable products in air, what we call combustion takes place, which is the common source of heating, by which the temperature of any particular body is increased. Fire gives warmth, because the combustible

part of the fuel, takes on a new form of existence, being chemically combined with the oxygen of the atmosphere, and heat is evolved. This source of heat, then, is due to a change of state in bodies, and is entirely limited by the amount of substance suffering change, and ceases when the change is complete.

During the chemical change the same sort of heat energy is liberated as that which is liberated in the animal system, while the gases are likewise set free. The only real difference between the two kinds of combustion is that in the animal system the process is conducted with an extreme degree of slowness, and we have a low degree of heat, while in the ordinary fire the combustion takes place rapidly, and the heat being evolved in a much shorter time is proportionately the more intense. In both instances, whatever increases the supply of oxygen, increases the intensity of the heat liberated.

HEAT IS MOTION.

What heat is we do not know. The now-accepted theory is that it is an immaterial force, resulting from the vibrations in the molecules of matter. The more rapid the vibrations the greater the heat. Though we know not what heat is, we have a knowledge of its laws, and the changes it has power to work on matter.

THE THERMAL STATE.

The state of a body with reference to heat generally may be designated as its *thermal state*, and when placed in communication with reference to heat, they may be said to be in a *thermal communication*. When of equal temperature, two bodies are said to be in *thermal equilibrium*.

DISTRIBUTION OF HEAT.

Heat tends to diffuse equally among bodies of a different temperature; that is, every vibrating atom tends to communicate its own rate of vibration to other atoms, and has its own motion lessened by the amount of motion thus communicated. It is diffused or transmitted from

one place to another by *Conduction*, by *Convection*, and by *Radiation*.

By *Conduction*, when the molecular vibrations are transmitted directly from one molecule to another touching it. If one end of a metal rod is placed in a fire, the other becomes heated by conduction.

By *Convection*, when molecules or atoms of matter in energetic vibration are actually conveyed from one part of a body to another, in sensible masses, others taking their place, and a circulation being thus established, as when water is placed over a fire. The heat that passes through such a porous substance as hair, wool, etc., does so to some extent through the agency of the air they contain, which, as it becomes heated in one portion tends to diffuse toward a colder, carrying its heat with it. This is a very slow process.

By *Radiation*, when the molecular vibrations are transmitted from one body to another not in contact with it, by means of undulations excited in an intervening medium. When the hand is placed before a hot object, it is heated by radiated heat.

INEQUALITY OF CONDUCTIVITY.

Bodies have the quality of conductivity in different degrees, those being called good conductors in which any inequality of temperature is quickly equalized, the excess of heat being transmitted with great facility from particle to particle before it is dissipated in other ways. Those in which it passes more slowly and imperfectly through the dimensions of a body, and in which, therefore, the equilibrium of temperature is more slowly established, are called imperfect or *non-conductors*.

Solid substances conduct heat in all directions, whether upward, downward, or sideways with nearly equal facility. Of all solids, those which are most porous conduct heat with the least rapidity. If some asbestos, a substance composed of certain silicates in a fibrous condition, be placed on the hand, and on the asbestos a live coal, the coal can be supported without inconvenience. The asbestos

intercepts the heat. Heat being motion, anything which disturbs the continuity of the chain of molecules along which motion is conveyed must retard the transmission ; hence division of a substance interferes with conductivity. In the case of the asbestos, the fibres of the silicates are separated from each other by spaces of air ; to propagate itself, therefore, the motion has to pass from the solid to the air, a very light body, and again from the air to the solid, a comparatively heavy body, and it is easy to see that the transmission of motion through this composite texture must be very imperfect. In the case of silk, wool, or an animal's fur this is more especially the case, for here not only do spaces of air intervene between the solids, but the solids themselves, unlike the fibres of the asbestos, are very bad conductors.

If a porous substance used for non-conducting purposes be either much compressed on the one hand, or too loosely applied on the other, they do not make so perfect a non-conductor. In the one case the particles, being brought into closer contact, transmit heat from one to another, and in the other case, the air, circulating too freely among them, air currents are established, by which heat is quickly diffused through the mass. To produce, therefore, the most perfect non-conductor, the particles of the body must have naturally little conductivity, and they must be sufficiently compressed to prevent the circulation of currents of air among them, and not sufficiently compressed to give them a facility of transmitting heat from particle to particle by contact.

HEATING BY CONVECTION.

While gases and liquids do not carry heat in all directions with facility, they may be easily and quickly heated by convection. Convection takes place when liquid or gaseous bodies have at a lower level a higher temperature than at an upper. When the lower strata of a liquid or gas is heated, expansion occurs, and the diminution of density causes the heated portions of the liquid to rise to the surface, while the colder parts sink to the bottom.

In this manner convection currents are set up which transport the heat from one part of the liquid to another, and tends to bring about a uniformity of temperature by diffusing it through the mass.

On the other hand, when the upper surface of the liquid is heated the lower strata can become heated only by radiation and conduction proper, or by the process of diffusion or molecular convection — that is, by the individual molecules of the liquid becoming heated at the top, and afterwards traveling into the lower strata, carrying their heat with them, and gradually parting with it to the colder molecules below by radiation or by contact, or by both processes simultaneously. When heat is applied to the upper surface of a liquid the flow of heat downwards is in general exceedingly slow, except in the case of mercury or other metals in the liquid state.

HEATING BY RADIATION.

To heat a space containing air from above would be as extremely difficult as in the case of water, were it not for the great mobility of such a gaseous body and its high diathermanous character. That is, owing to the mobility of gaseous bodies their particles move about with great readiness in response to the slightest impulse or force; while owing to their extreme rarity they freely transmit radiant heat.

In proceeding from hot bodies, heat rays are propagated through space in straight lines, in the same manner as rays of light; and they are, in like manner, subject to transmission, reflection, and absorption in various degrees by such bodies as they encounter.

In radiation the motion of the molecules is supposed to be communicated to another body by means of the motion of the intermediate ether which is supposed to fill universal space and the interstices between the molecules of matter.

SIMULTANEOUS RADIATION AND ABSORPTION.

Radiation depends only on the body itself, while the absorption depends on the nature of the body itself as well as on the condition of neighboring bodies.

In order to illustrate this point let us consider the case of a thermometer suspended in a warm room at a steady temperature. In this case all the bodies in the room are radiating heat, part of which is absorbed by the thermometer, and if the temperature of the thermometer is stationary, the quantity of heat absorbed by it is balanced by an equal radiation. If now a cold body be brought into the room and placed in the vicinity of the thermometer this body will screen the thermometer from some of the radiation which previously fell upon it, and will not itself radiate an equal supply. The total radiation received by the thermometer will consequently be diminished. The equilibrium which previously existed will thus be broken, and the temperature of the thermometer will fall to that point at which its emission is precisely equal to its absorption under the new circumstances.

This is a case of what was erroneously designated as the radiation of cold. It illustrates how equilibrium is reached and maintained, not merely by the warmer bodies radiating and the colder absorbing, but rather by the mutual process of simultaneous emission and absorption. It also illustrates how largely the indications of a thermometer depend on the nature of the radiation of the bodies around it as well as on the temperature of the medium in which it immersed. The indications of a thermometer may differ very much from the temperature of the air at the point where it is suspended.

SPECIFIC HEAT.

The relative amount of heat which a body receives in reaching a given temperature is called its specific heat, or its capacity for heat. If we put a pound of water, a pound of olive oil, and a pound of mercury before a fire, it will take twice as long for the water to gain one degree in temperature as it will the oil, and thirty-three times as long as the mercury, because the oil only requires one half the heat to raise it one degree of temperature, and mercury but one thirty-third as much as the water.

The thermometer does not register the specific heat. The temperature of water from melting ice is the same as ice, yet it contains twice as much heat. Water gives off heat when freezing, and absorbs heat when melting.

APPLYING HEAT TO THE EGGS.

In natural incubation the eggs are placed beneath a heat-generating body, and covered in with down and feathers. In this position they are warmed principally by conduction, and secondarily by diffusion or conveyance — both interior and exterior of the shell.

An unincubated egg is a very poor conductor of heat. The shell, however, is one of the very best conductors, and to it the more uniform heating of the egg is at first due. In illustration, if a piece of muslin be smoothly wrapped around an egg, it may be held in the flame of a lamp until the whole egg is hardened without the muslin's burning, so rapidly does the shell conduct the heat away.

In addition to the high conducting power of the shell, through the rapid development of the vascular system, the blood circulation soon aids in the distribution of the external warmth. Moreover, in natural incubation we have supplementary external aids of considerable value; *i. e.*, the tendency of the heated air to diffuse downward through the feathers covering in the eggs, as well as outward, and of the feathers to hold, entangled around the eggs, a comparatively large volume of warm air. The air in contact with the heating body becomes warmer than the outside atmosphere, and tends to diffuse outward through the feathers, cooler air taking its place, though any rapid movement is held in check by frictional resistance. Thus it is seen that the heat is to a large extent retained around the eggs by the maze of fluffy feathers.

TEMPERATURE OF THE EGGS.

I find the temperature of the eggs will average up at the end of the first day of incubation at about 97 1-2 degrees. At the end of the second day at 98 1-4, and from

this time on will gain uniformly one-fourth degree a day until the end of the eleventh day, having a temperature at that time of about 100 1-2 degrees. During the next two days the temperature rises to 101 1-2 or 102 degrees, and remains more or less stationary at 102 until the end of incubation.

The eggs tested were from a mixed lot of hens, and the sitters were common barnyard fowl. The figures given are the average of from five to eight registrations each, and represent, for the most part, the temperature of the great mass of the egg only, the temperature of the blood in the vascular system probably being somewhat higher.

A SPECIAL THERMOMETER.

The thermometer used was made especially for the purpose, and contained the least possible mercury, and had the largest amount of surface exposure that it was practicable to make. The instrument was so delicate that it would register from four to six degrees above the temperature of the air when exposed to the radiant heat an inch from the palm of the hand, and was sufficiently delicate to show a difference of half a degree in different parts of the egg.

GETTING THE TEMPERATURE.

In testing, the egg was removed from the nest and wrapped in warm flannel; a small hole, about one eighth of an inch in diameter, was cut in the broad end of the egg, and the thermometer, already warmed to 98 degrees, was quickly introduced into different parts of the egg without mixing the contents any more than possible. A correction of two-fifths of a degree was allowed, which probably more than covered the amount of heat lost. A difference of half a degree could be detected between the temperature of the centre of the egg and the parts near the surface, while one side seldom registered as much as one-fourth degree higher temperature than the opposite. Only eggs that were well covered were taken, and only those containing live germs counted. Unfertilized eggs ranged from 96 to 98 degrees throughout the hatch.

The one or two fertile eggs left in the nest in each sitting hatched by or before the close of the twenty-first day, and in all but three dead germs were found. All the eggs showed a remarkable uniform temperature at the different periods, seldom varying as much as one degree either side of the figures given.

PROBABILITIES.

Notwithstanding the delicacy of the thermometer used, it is probably impossible to get the temperature in the region of the germ-spot, or later of the blood in the vascular system before the twelfth day, with so crude an instrument as a thermometer. The egg undoubtedly attains a superficial temperature at first of 100 degrees over that portion which is in immediate contact with the incubating body, and during the first days of incubation the germ must partake of that temperature to a greater or lesser extent, as it lies immediately beneath the shell in the neighborhood of that portion which is nearest the source of warmth.

THE MAXIMUM TEMPERATURE.

The great body of the egg, however, does not reach its maximum temperature until the twelfth or thirteenth day. By this time the allantois extends three fourths of the way around the egg, and its blood-vessels lie immediately beneath the chorion and shell membranes, while the vessels of the yolk-sac have nearly enclosed the yolk. It will thus be seen that the heat applied to any one portion will at this time be rapidly diffused by the blood throughout the contents of the egg.

TEMPERATURE OF THE HEN.

If during the first few days of incubation we place a suitable thermometer beneath the hen, in about the same position as the eggs are placed, there will be imparted to it a temperature of about 101 degrees only, although a glass placed in the rectum will register from 109 to 110, and if the hen is killed without bleeding, an opening quickly made through the side, and a delicate thermome-

ter thrust into the region of the heart, it will register from 112 to 112 1-2 degrees. By the end of the first week of incubation the temperature in the rectum will be about 109; by the end of the second week it will have fallen to 108; and sometimes by the end of the third week to 106 degrees. One hen with a rectum temperature of 106 at the end of incubation was killed the fourth day following, and was found to have a temperature in the region of the heart of 110.

RELATIVE POSITION OF THE EGG.

During the early stages of incubation the eggs cannot be said to be, to any great extent, in direct contact with the incubating body, as a layer of down and feathers intervenes; but, as incubation progresses, the feathers covering the abdomen either fall or are plucked off, and the eggs are then brought in direct contact with it; so that, notwithstanding the greater body temperature of the hen at the commencement of incubation, the temperature of the surface which imparts the warmth to the egg is not much inferior during the later stages of incubation to that of the earlier, owing to the change in the relative position of the egg, and to the greater advancement of the incubating plexus, which brings more and more warm blood to the surface of the abdomen.

HEAT IS DEVELOPED.

The eggs themselves develop very little heat up to the eleventh day. By the eleventh day the structural development of the chick is about complete, and from this time on less external warmth is required to maintain its temperature; a small amount of heat being now developed by the chick in the absorption and oxidation of the remaining nutrient material, the chick growing rapidly, and some little excretion appearing in the allantoic fluid and in the intestines.

HIGHER SUPERFICIAL TEMPERATURE.

Although up to the twelfth or thirteenth day the great mass of the egg has a somewhat lower temperature than

102 degrees, it is probable that it has a superficial temperature in the neighborhood of the germ of from 100 to 100 1-2 degrees even at the first. This assumption is based upon the fact, noted from a series of careful experiments, that if the eggs are maintained at a temperature rising from 98 to 100 degrees, the development at seven days is from twenty-four to thirty-six hours behind that of the same period under natural incubation. When the eggs are incubated at an initial temperature of 100 1-2 degrees, gradually rising to 102 by the eleventh day, and maintained at that degree for the balance of incubation, the chicks are usually all excluded by the middle of the twenty-first day; that is, if the eggs are not subjected to too frequent and prolonged exposure to a cold atmosphere. In the latter case the eggs will need to be maintained at a higher temperature during the entire period. When the eggs are maintained at a temperature of 100 1-2 to 102 degrees, and subjected to little or no exposure to a cold atmosphere, the embryonic development is found to correspond approximately to that under natural incubation.

COOLING THE EGGS.

If an abundance of food and water is placed where it will be accessible to the hen when she leaves the nest, it will be found that, if left to herself, a successful sitter remains on the eggs two, three and even four days at a period without leaving them. In exposing eggs to the atmosphere two facts must be taken into consideration. When the hen returns to the nest the eggs quickly regain their normal temperature; while, when the eggs are removed from an incubating chamber under artificial incubation, they are some time warming up when replaced. Under the influence of an atmospheric temperature of 65 degrees the eggs, during the early stages of incubation, will lose heat at about the rate of one degree each two minutes. Under an atmospheric temperature of 35 degrees they will lose more than a degree a minute. When replaced in the incubating chamber it takes as long as one, two or even three hours to regain the desired

temperature, the length of time required depending on the degree to which the hatching chamber as well as the eggs were cooled. It has been held that the eggs need to be cooled in order to absorb fresh oxygen, but this view arose through ignorance of the laws controlling the movement of gases, and is entirely fallacious.

EGGS DIFFER.

Eggs from different breeds will vary in the time required for incubation ; the eggs from the lighter and more active breeds usually hatching in somewhat less time than those from the heavier and less active. Different eggs from the same pen and breed of birds, however, will vary as much as fifteen hours in the time required for the exclusion of the chick. This fact probably accounts for a part of the difference in temperature of two eggs lying side by side under a hen ; as the difference in temperature cannot be entirely due to the difference in position. I find two fertile eggs lying side by side in an incubating chamber sometimes vary as much as a full degree during the earlier stages of incubation. In this case, however, a part of this variation is due to a physical difference in the eggs, as well as to a difference in position of the eggs in reference to the heating surface, cooler walls, and unfertile eggs.

THE CORRECT TEMPERATURE.

In view of the fact that when the eggs are incubated at a gradual rising temperature of from 100 1-2 degrees to 102 by the eleventh day, the embryonic development corresponds approximately to the development under natural incubation, we can reasonably infer that this is the temperature at which the eggs should be maintained. When incubating at a temperature of 100 degrees for the first three days ; 101 for the next four ; 102 for the following five ; and 103 for the balance of incubation, the chicks are excluded from the middle of the nineteenth to the middle of the twentieth day ; but at the seventh day the development is about equal to that under natural incubation. In incubating at a temperature of 101, 102,

and 103 degrees respectively for the three weeks required, will also exclude the chick too early ; but the difference in development from that under natural incubation at the earlier periods is not particularly marked.

The reader will bear in mind that the temperature of the egg is spoken of, and not that registered by the thermometer.

EXTREME TEMPERATURES.

Eggs will stand considerable variation in temperature before the life of the germs are destroyed. During the earlier stages of incubation the development will proceed slowly under a temperature of 98 or 99 degrees, no more dying, if as many, as when incubating at a temperature of 101 ; and, if the heat is gradually raised, the chicks grow quite rapidly during the later stages, and are excluded on time.

A high temperature during the earlier stages of incubation, however, is usually fatal. This is undoubtedly due to too rapid chemical changes in the protoplasm under the influence of a high temperature, causing undue cell metabolism. The opposite to this probably occurs when the germ starts to develop under a low temperature (80 or 85 degrees), and the vital spark is extinguished.

After the eleventh day a temperature of 110 or 112 degrees, if not too prolonged, is not necessarily fatal. At this time the temporary embryonic appendages — the circulation of the yolk-sac, or digestive system, and the allantois, or lungs — are about completed, and the surplus heat is taken care of in somewhat the same manner, although in a much inferior degree, as in the adult system. The greatest excess of heat for a short period can probably be withstood after the sixteenth day, when the growth of the allantois is completed.

SLOW DEVELOPMENT.

In the above paragraph the germ is spoken of as starting to develop. Strictly speaking, the germ starts to develop before the egg is laid, and probably does not entirely cease until the vital spark is extinguished, or the chick is

excluded. Perceptible changes occur under the influence of a temperature of 80 degrees, and as the temperature is raised, the more rapidly do these changes take place.

KEEPING EGGS.

Just how long it will take to destroy the germ under the influence of different temperatures, I do not know. I have not had time to thoroughly test the matter, and I know of no one having done so. From the data at hand, however, it is quite probable that eggs may be kept for a period of four weeks and still retain their full vitality. This is a little longer period than that required by the domestic hen to deposit a batch of eggs and to commence to incubate, and about the period required for a partridge and other similar large game birds, whose eggs are usually deposited in a slight hollow of the ground, and without protection of any sort, are subjected to the various changes in the elements common to the incubating period.

With the megapode, the eggs are covered up as deposited, and given the protection thus afforded. The hatching mounds seem to be so constructed and timed by the parent bird, however, that it does not heat up to any extent until after the eggs are all deposited. They are subsequently subjected to a gradual warming up, and not to a continuous high temperature.

There is no exact data on the habits of the ostrich in the wild state, but its eggs are found to hatch under artificial incubation at the common incubating temperatures, which seems to be the case with nearly all birds' eggs, although this temperature is probably as far from the natural as the artificial conditions are unlike the natural.

A VARIABLE TEMPERATURE.

The preponderance of evidence is, in fact, that all eggs allow of a considerable latitude in the incubating temperature, but only when other conditions are equal.

Our wild duck, the little grebe or dab-chick, for instance, leaves its eggs to the mercy of the variable heat of the sun and decaying muck during the day, and incubates only at night; while the tern is accredited with not incu-

bating at all, but leaves its eggs to hatch by the heat engendered in the decaying muck of an abandoned muskrat hole and the heat of the sun, without any special provision more than giving the eggs a thick coat of mud. No one acquainted with the variable temperature of a spring northern Ohio will assert that in either case the eggs are subjected to an even incubating temperature. The climate where the Egyptian hatching ovens are constructed is about as variable as at Jacksonville, Florida. In both places the temperature varies as much as 36 degrees in twenty-four hours — not an equable temperature, surely. The walls of the mamals are usually constructed of sun-dried brick of considerable thickness, and are capable of withstanding considerable variation in temperature. That there must be some variation in their inner temperature in such a variable climate, however, is obvious.

The foregoing facts show something of the extreme conditions under which eggs can be placed, both before and after incubation commences, and still retain their vitality, and, other conditions being equal, capable of producing a live bird. Nevertheless, there is unquestionably a certain temperature at which eggs may be kept for the longest period without effecting their vitality, a certain incubating temperature to be maintained for the best possible results to be produced, and certain mechanical and atmospheric conditions to be observed from the time the egg is laid until the exclusion of the chick. Simply because a puppy will live for fifty minutes under water, are we to leave him out in every shower; or, because the human body can exist under a temperature of 300 degrees in a dry air, do we wish to run the temperature of our living rooms up to that degree two or three times a day? The vicissitudes of temperature, climate, and other conditions under which living organisms will continue to exist, are extreme, indeed, and the limitations are usually proportioned to the changes the individual has normally to withstand; but in all organic life the highest development is only attained under particular, narrow, and usually well defined limits.

THE TEMPERATURE AT WHICH TO KEEP EGGS.

In determining the temperature at which eggs for incubating purposes should be kept, we shall need to first consider the effects of a greater or lesser temperature.

We know that the germ development is continuous with fecundation, and that after the egg is laid and its temperature allowed to fall to 50 or 60 degrees the germ lies nearly dormant, but not entirely so, for eggs kept two weeks at a temperature of 60 degrees will incubate in several hours' less time, on an average, than newly laid eggs. If the temperature is gradually raised from 60 degrees, metabolism grows more and more rapid, and at 102 the process of incubation may be said to be at its height.

If the germ does not lie absolutely dormant at 60, and a greater temperature causes a more rapid development, under a lower temperature we may reasonably expect metabolism to be still less active. Undoubtedly this is the case, and if so, the lowest temperature consistent with the continued life of the germ is the degree at which the eggs should be kept.

If the egg be frozen, the constituent cells of the blastoderm and food-yolk are disarranged and broken up, and the vital spark extinguished, and, upon thawing out, the egg quickly becomes putrid.

The freezing temperature is too low a degree, therefore, at which to maintain the eggs, and, as the first effect of this temperature is produced at 39 degrees, it is obvious we should not allow the eggs to fall below, if quite to this point. Forty degrees may, therefore, be named as the theoretical temperature at which the eggs should be maintained before incubating if they are to be kept for the longest period.

MANNER OF KEEPING EGGS.

Many opinions have been expressed as to the manner in which an egg should be deposited and handled when keeping for incubating purposes. Some advise standing on small, and some on the large end; while others, to stand on end and reverse the position every day. The

theory has been that if allowed to remain in one position, the yolk, being heavier than the albumen, would cut through and stick to the shell, and it was thought that if stood upon end and turned from day to day this would be prevented.

The striking error in this theory is in regard to the weight of the yolk. The yolk is specifically lighter than the albumen, and would no quicker cut through the latter than a cork would sink in water. In fact, the yolk is buoyed up by the albumen, and the germ, which always lies on top, is only kept from pressing against the shell by the weight of the denser albumen forming the chalaza, the latter having a tendency to drag the yolk down and steady it.

If the eggs are kept for too long a period at too high a temperature, the albumen gets somewhat fluid, its arrangement is broken up, and the yolk is then pressed upward with some force against the shell, and if allowed to remain in this position will eventually dry to it.

It is probable that any period of time and degree of temperature sufficient to break up the natural arrangement of the albumen would destroy the vitality of the germ; and the egg would be useless for incubating purposes whether or not the yolk was dried to the shell. It is obvious, too, that the more handling the egg receives, the quicker will this disarrangement be effected.

I have had no occasion to keep eggs for a longer period than three weeks, and know of no reason why they should be kept for a longer one. When keeping eggs for this period, and also for shorter ones, they have been placed in a basket or box of some sort without any regard to position, covered over with a cloth to check any draft that might strike them, thus preventing undue evaporation, and left undisturbed until wanted. Any cloth will give sufficient ventilation to keep the air around the eggs sweet; that is, if the air in the apartment in which they are kept is pure. The cellar in which I keep eggs is dry, and varies in temperature during the fall, winter and spring from 35 to 65 degrees.

When incubating without turning the eggs, no difference has been observed in the number of germs dried to the inner membrane when the eggs were stood on broad end or laid in their natural position ; almost twice as many, however, will dry to the membrane separating the albumen from the air space in the broad end when the eggs are placed on the small end.

APPLICATION OF HEAT.

As was shown in an earlier part of this chapter, 100 1-2 degrees at the initial stages, gradually rising to 102 degrees by the eleventh day is probably the correct incubating temperature for hen's eggs. We have now to consider how we are to maintain them at that temperature. The atmospheric conditions to be maintained during incubation will be discussed under the head of ventilation.

In artificial incubation an equable distribution of heat over a comparatively large surface is first to be desired. This is very difficult of attainment, the reasons for which are obvious.

In the first place, as a basis of discussion, let us take an incubating chamber say thirty inches deep, fifty inches long, twelve inches in height, with egg trays placed five inches from the bottom. Such a chamber will hold about 400 eggs. This is as large as it has been found practicable to make a hot air machine, and about as small as it is economical to make one heated through the agency of hot water. We will say the heating body comprises the entire upper surface of the chamber.

To uniformly heat a surface 30x50 with hot air is difficult, on account of the low specific heat of air. Air containing but little heat, it has little to give off before falling through several degrees of temperature. The specific heat of water is high, and although water flows much slower than air, it can travel over a considerable area before parting with as much as one degree of heat.

AN UNEQUAL TEMPERATURE.

We will now suppose the heating surface has been brought to a uniform temperature by some means, and

all the direct heat rays given off of equal energy. If we now place several thermometers in the machine, and note their temperature, we will find those in the centre registering the highest, those a little farther towards the sides a lesser temperature, and those nearest the sides the lowest. It is evident then the sides are giving off less radiant energy than they are absorbing, causing a loss of heat to the chamber. As it is quite impracticable to make a case that is a perfect non-conductor, we shall always have this feature to contend with.

The loss of heat energy is felt to the greatest extent in that portion of the chamber near the sides, for the reason that radiant heat diminishes in intensity as the square of the distance from the radiating surface increases. The distance being the greatest at the centre of the chamber from the surface where the loss of warmth occurs, that portion is the least affected.

AIR CURRENTS.

The air within the chamber is warmed by coming in contact with the various hot surfaces, and air currents are established which travel in almost every direction. Where there are extreme inequalities in the radiant energy at different points within the chamber, the movement of the air tends to equalize the temperature, and does so to a moderate extent ; but as long as there is a source of heat within the chamber, just so long will inequalities of temperature be found in the air, as well as in the other bodies within the chamber. This is the case even where the radiant heat is to a large extent equalized by creating inequalities of temperature in the heating surface.

Air currents may, to a large extent, be prevented from striking the eggs by making the sides of the egg trays of some height, say four inches ; and partitioning them off in divisions of about seven inches square, or say to hold fifteen eggs each. By this means the temperature of the eggs will be less affected by that of the air within the chamber ; or rather, the air around the eggs will

partake to a greater extent of their temperature. The partitions should be made of as thin material as is found practicable to make them, that they may take up as little space as possible.

The direction of the air currents may be controlled by certain systems of ventilation, but this only excites a more rapid movement of the air, which does more harm than the inequality of temperature.

EQUALIZING THE RADIANT ENERGY.

We will now consider the effect of equalizing the radiant heat within the chamber by creating inequalities of temperature in the heating body. This may be done for any particular temperature, by directing the flow of hot water or air over the heating body, but the same inequalities will not answer for all temperatures. For instance, we will say that the temperature of the air around the machine is 80 degrees, the highest atmospheric temperature in which any machine should be operated.

At this temperature the loss of warmth through the medium of the walls or casing of the chamber is at its minimum. We now direct the flow of hot fluid in such a manner that it warms the heating body near the walls of the chamber to a certain degree of temperature above that at the centre, the temperature of the intermediate points being graduated proportionately. If we have correctly estimated the difference in temperature required, we will now find that the greater radiant energy given off by the heating body near the walls of the chamber offsets exactly that which is absorbed, and thermometers now placed in different parts of the chamber will show that they are all receiving the same amount of radiant heat.

We will now take this machine, the hatching chamber of which was equally heated when surrounded by an atmospheric temperature of 80 degrees, and place it under an atmospheric temperature of 35 degrees, about the lowest temperature in which any machine should be operated. The loss of warmth is now at its maximum, and we find

that the greater warmth of the heating body near the walls of the chamber no longer offsets that absorbed. We shall therefore need to increase the inequality of temperature of the heating body under the new conditions. It is thus obvious that an incubating chamber cannot be constructed so that it will maintain the eggs at an equable temperature under all conditions, and that the best we can do is to construct the chamber so that it will have an equable temperature when placed in the mean of the atmospheric temperatures in which it is going to be operated. If this is done, and the walls are properly constructed, the greatest variation need not be more than a degree, or possibly a little less. The corners will show the greatest variation, for the reason that the surface of absorption (the wall area) is relatively larger at these points than the surface of the heating body. A round chamber would be the model shape, but this would be impracticable to construct, besides being inconvenient to operate.

OFFSETTING INEQUALITIES OF TEMPERATURE.

To offset any differences in temperature, the relative position of the eggs should be reversed. This may be quickly done by simply turning the trays around so that the cool side takes the place occupied by the warmer. If this is done twice a day, say when the eggs are turned, a difference of a degree in temperature will do no harm. Even greater differences of temperature in the different parts of a machine may be offset, to a great extent, by shifting the location of the different trays.

RELATIVE TEMPERATURE OF THE EGGS.

We will now follow the relative temperature of the eggs through a period of incubation. Let us suppose the hatching chamber has an equable temperature, and the temperature of the heating body, as well as that of the outer atmosphere, to remain stationary throughout the entire period. From our present point of view all the eggs would thus be under perfect thermal conditions if they were at the proper temperature to start with.

During the first ten days of incubation the metabolic changes are directed toward the building up of the embryonic structure, little energy being given off in the form of heat. During this period there is, therefore, nothing to disturb the relative temperature of the eggs. About the eleventh or twelfth day of incubation, the embryonic structure being about completed, catabolism, or destructive metabolism becomes somewhat active, and heat energy is liberated, which increases the temperature of the fertile eggs. As the unfertile eggs can generate no warmth, they now absorb some of that generated by the fertile eggs opposite them, the latter being prevented from gaining a temperature equal to that of the fertile eggs surrounded by heat-generating eggs like themselves. The unfertile eggs should, therefore, be removed by the tenth day.

SPREADING THE EGGS OUT.

After removing the unfertile, the fertile eggs should be spread out so as to occupy about the same relative position to one another. If this is not done the temperature of the eggs will vary quite considerably. That is, the eggs in a full tray will have a higher temperature than those in one but half full. A number of eggs bunched together in one end, even, will have a higher temperature than the few that may be scattered over the remaining portion of the same tray. The difference in temperature may only be a degree or two, or even less, but whether or not artificial incubation is successful depends upon an equable temperature more than any other one thing.

AN APPROXIMATE AIR TEMPERATURE NECESSARY.

The reader will appreciate the force of the above remarks better, if he has not already observed the inequalities of temperature under the conditions cited, by bearing in mind the fact that, though the eggs attain their temperature through the agency of radiated heat, it is necessary for its maintenance that the medium around them

has an approximate temperature, as otherwise their heat would be too quickly carried away. The eggs and nearby surfaces receive the radiant heat, become warm, and impart a portion of their warmth to the air which is banked up around them by the walls of the chamber. This process is carried on, the eggs gaining warmth from the heating body above, and the air in turn receiving it from the eggs, until the loss of warmth through the walls just offsets that supplied to the heating body. When the eggs begin to generate heat, a portion is given off to the air.

If now we have a full tray of heat-generating eggs, all these eggs take part in warming the air about them, and the loss to each egg is proportionately slight. On the other hand, if there are but a few eggs scattered about, there is a larger body of air for each egg to warm, and the loss of heat by each egg is greater, and their temperature falls below that of the eggs where there are a number together. Thus it is seen that unless the eggs are evenly distributed in all the trays an equable temperature cannot be maintained.

HOW THE AIR IS WARMED.

The air in the incubating chamber is warmed by coming in contact with the various warm surfaces therein, some of which have a higher temperature than others; but, on account of the surface having the superior temperature being at the highest point within the chamber, the air partaking of this temperature can rise no farther; as it would do if not restrained, being buoyed up by reason of its lesser weight. This warmer strata of air, floating in the upper part of the chamber, cannot easily fall to the level of the eggs in a mass, though a small body of it is occasionally carried downward by currents and eddies, but only to quickly rise again. Though some warm air is carried downward by molecular diffusion, the bulk of the warmth attained by the air on a level of the eggs is gained by coming in contact with these bodies, as well as the trays, etc.

THE HEAT MUST BE REGULATED.

Up to the present time we have spoken of the eggs as being subjected to a certain fixed degree of heat, imparted to them by a fixed temperature in the heating body above under a fixed atmospheric temperature. This is practically a theoretical condition, for in practice we will need to regulate the temperature of the heating body so that the heat given off by it will be just sufficient to offset that lost by the chamber when placed under various outer atmospheric temperatures. We can reduce the temperature of the air and eggs without reducing the temperature of the heating body by giving more ventilation, and thus replace the warmer air with that of a lesser temperature ; but this method is not a desirable one, the reasons for which will be cited when considering the subject of ventilation.

Before considering the regulation of the temperature of the hatching chamber, however, we will need to know when its temperature is at the desired degree ; or what is of more importance, and sometimes considerably harder to ascertain, what is the degree of temperature of the eggs.

A GOOD THERMOMETER.

To start with, we shall need to secure a good thermometer. Many comparatively new glasses are still put out, and after the tube ages they register half a degree or more high. This will not make much difference if we know what the correction is. In scientific work requiring their use the thermometers are always tested from time to time, and the correction ascertained. After a thermometer is a year and a half or two years old, further aging will change it very little. A new glass will change the most during the first six months, at which time some manufacturers graduate and place on the market.

There should always be a good standard thermometer on every place, and when a new glass is bought, it is easy to learn the correction, if any, and to test it from time to time afterwards. A good way to test a thermometer is

to place it, together with one known to be correct, in a body of water which has been previously heated to 105 degrees. Allow the water to cool down gradually, and note the temperatures of the two as they fall through five degrees. The water will need to be continually stirred, for otherwise all kinds of temperatures can be detected in it, and we would not know when the two thermometers were receiving a like amount of heat.

THE AIR TEMPERATURE.

The relative temperature of the air and eggs does not remain the same excepting under like conditions. Their temperatures are never equal, and changes in amount or method of ventilation will widen or lessen the difference in their temperature. To ascertain the temperature of the air around the eggs, we shall need to wrap the bulb of the thermometer used in a considerable amount of cotton batting, or a similar non-conducting substance of low specific heat and of considerable bulk and a loose texture, and stand it up in the tray in the place of an egg. The thermometer used for this purpose should be mounted on wood alone, or otherwise the metal will conduct a considerable amount of heat to the region of the bulb, and it will register a higher temperature than the air.

THE TEMPERATURE OF THE EGG.

To ascertain the temperature of the egg without breaking it is impossible with the use of a thermometer. If we place a thermometer so that its bulb rests upon a fertile egg, it does not necessarily give us the temperature of that egg. In fact, it will sometimes register as much as two degrees higher than its temperature during the earlier stages of incubation, and sometimes after the eleventh day the temperature of the egg rises as much as one half of a degree above that shown by the thermometer. The difference in temperature between the thermometer and egg will be determined by the temperature of the heating body. In cold weather, when the temperature of the heating body is the greatest, there will be a differ-

ence of 1 1-2 to 2 degrees during the initial stages of incubation; while when the atmospheric temperature is high, and that of the heating body correspondingly low, the thermometer with its bulb on a fertile egg will show a temperature only 1 to 1 1-2 degrees higher than that of the egg.

During the later stages of incubation, when the temperature of the heating body is not only influenced by the atmospheric temperature, but by the number of fertile eggs contained in the chamber, the temperature is more difficult to determine. Moreover, the temperature of the heating body will need to be greater at all times in a machine with poorly constructed walls, than in one with first-class non-conducting walls. If we know the temperature of the heating body at all times we can estimate the temperature of the egg, but very few machines are so constructed as to render this possible. It is thus seen that we have no degree of temperature that is at all constant by which to regulate the heat of the chamber. There needs to be a nice balance between the heat and atmospheric conditions, and if the balance is maintained it is possible to successfully incubate eggs under the influence of a temperature two or more degrees either side of 102. In the ordinary incubating chamber both the temperature of the eggs and the atmospheric conditions have been allowed to vary, and the only wonder is that many have been able to succeed so well in getting out a large percentage of the fertile eggs. It only shows under what extreme conditions an egg will sometimes hatch.

With the machines as now constructed, and atmospheric conditions that will be given when considering the subject of ventilation, the relative temperature of the egg and the thermometer with its bulb resting upon it, will average about as follows:—

During cold weather (35 degrees) the egg is generally found to be about 1 3-4 degrees lower than that shown by the thermometer during the initial stages of incubation, while during the later stages the thermometer ranges from an equable temperature to 1-2 a degree lower than the egg.

During the warmer weather of fall and spring (60 to 65 degrees) the egg will have a temperature 1.4 degrees below that of the thermometer during the early stages; and during the later the relative temperature is about the same as during colder weather.

When the thermometer is placed upon a fertile egg, and its temperature maintained during the entire period of incubation at 102.1-2 degrees during the colder weather, and 102 degrees during the warmer, the embryonic development corresponds closely with that with the hen incubating. When the thermometer is laid on the eggs, but with its bulb free, or where it is stood up among the eggs, its temperature is exceeding variable. With the atmospheric conditions anywhere near constant, the placing of the bulb on a fertile egg gives as even a relative temperature as can be obtained by a free exposure of the thermometer.

The general indications may be briefly summed up as follows:—

The higher the temperature of the heating body, the greater will be the difference between that of the egg and thermometer during the initial stages of incubation; and *vice versa*: the thermometer registering a higher temperature than the egg. During the later stages, as the temperature of the heating body falls to nearly that of the eggs the two temperatures are gradually equalized; and if there are a large number of fertile eggs incubating in a well constructed chamber in warm weather the temperature of the heating body falls to, or a little below that of the eggs, and the temperature of the eggs then rises above that of the thermometer.

HEAT REGULATORS.

We have now come to the regulation of the heat. I would like to say here that whatever may be said regarding the various devices used for the regulation of heat, that a regulator does not make a successful incubator. A machine may have a first-class regulator, and still be worthless as an egg hatcher; and, on the other hand, the regu-

lator on the machine may not be the very best that it is possible to make, yet the machine may give good results, owing to its meeting the other requirements more nearly. Other things being equal, however, the machine that has the best regulator has the advantage over its competitors.

The best heat-regulating devices are not put on incubators, they are too delicate of operation for general use ; the same as the delicate balance used by the chemist in making a quantitative analysis would be of little use to the merchant for weighing out sugar. The apparatus that the merchant uses, however, is sufficiently accurate for his purpose, and the heat regulating device we adopt will need to be sufficiently accurate for ours.

THE THERMOSTAT AND ELECTROMAGNET.

In making a comparative analysis of the merits of a great number of different heat-regulating devices, the one that stands out distinct and alone, superior to all others in its delicacy of action, is the combination of a thermostat with an electromagnet. It is the only regulator that has been so far put on the market that will regulate heat to a small fraction of a degree. This regulator is too delicate, however, for general service ; while its cost is almost as great as all the rest of the material in some incubators.

THE BAR THERMOSTAT.

The next in delicacy and probably the first in general utility, is the hard rubber and steel thermostat. Many thousands of dollars have been expended by different individuals in trying to get a thermostat powerful enough to do work, and still be sensitive and accurate. The principle under which a thermostat works does not allow of any restraint being placed upon its free action, and all attempts to make it do much work must meet with failure. It can be made to work a perfectly frictionless apparatus, but it cannot be made powerful and sensitive too. Then again, the more powerful it is made, the less

movement does it give off, and the movement given off will need to be multiplied a greater number of times to accomplish any result. In multiplying the movement we also multiply the work to be done, we add to the loss of movement in the transference and there is nothing gained. A thermostat fourteen inches in length is as long as it is practicable to make one. If made longer it will not return to the same point under a like degree of heat. A thermostat fourteen inches long gives but 1-16 of an inch movement to a degree of heat, and it must be made of very light material to give this movement. If such an instrument be attached to a lever working the heat reducing device, the lever will need to be very delicately counterpoised or the movement will not be uniform. The more so, for the reason that a movement of 1-16 of an inch to a degree of heat is of no practical service unless it is multiplied.

Whether the thermostat makes a good regulator or not, depends entirely upon the freedom and ease of movement of the heat reducing mechanism. It can be made to hold the temperature to half a degree, but more generally it will vary as much as a degree and a half. The main point to be guarded against in its use is to see that no restraint is placed upon it when the chamber is allowed to cool down. If there is, it will spoil the working of it in a very short time. After a time the thermostat that is made to do work become less affected by the heat, giving off less motion. It can be restored in part by tightening up the rivets.

Where the thermostat is made to do practically no work its motion is uniform, always going back to the same point under the same degree of heat. It makes a good thermometer, and many hundreds of them are in use for this purpose.

THE SINGLE RUBBER BAR.

The expansion of a straight rubber bar is sometimes used to work a lever. In this case there are generally two or three lengths passing through the chamber, the

motion of one being communicated to the other by short levers, the last one being attached to the lever that works the heat reducing device. With this thermostat the motion is so slight that nearly all of it is lost in the transference, and the little that is left is of no service, as it requires to be multiplied too many times. The greater number of times a given motion is multiplied by a lever, the less uniform is the amount of motion given off.

THE BALANCED THERMOMETER.

Another form consists of a balanced thermometer that, under the movements of the mercury in a tube pivoted in the centre in a horizontal position, rises or falls, and thus controls a lever that works the heat-reducing device. There are several patterns made, none of them being of any practical service to do work.

THE LIQUID THERMOSTAT.

A form of thermostat that is used for incubator and various other purposes consists of a thin sheet metal capsule containing fluid of a low boiling point. For incubating purposes this regulator is of little value. The boiling point of a liquid under pressure will vary considerably, though the pressure remains constant. Under the usual conditions this regulator will require two degrees of heat to work it. A constant variation of two degrees is not necessarily fatal to successful incubation, but the best results cannot be obtained under such circumstances. There is one degree variation in the relative temperature of the eggs when the heat is almost absolutely constant, besides the usual inequalities of a degree or more to be found in almost all large machines, and if a greater amount is added to this it obviously is not desirable.

Again, the boiling point of a liquid being determined by the pressure upon it, changes in the atmospheric pressure runs the usual variations of two degrees up to four or five. The atmosphere exerts a pressure sufficient to raise mercury in a tube from 27 to 31 inches, these being the usual extreme variations. The common variations

are about two inches, which is equal to about one pound pressure to the square inch. The atmospheric pressure is varying somewhat all the time, the greater variations being in winter when the machine is most in use. Every change which occurs in the atmospheric pressure will cause the heat to rise or fall.

WE HAVE NO FIRST-CLASS REGULATOR.

The above are about all the regulators that are now in use that are influenced by dry heat; that is, regulators dependent upon the heat of the hatching chamber for their action. This is the only method by which the temperature of the hatching chamber can be maintained constant under all conditions; and, outside of the bar thermostat, and the thermostat and electromagnet, we have yet to invent a regulating apparatus that will maintain it within a degree under all conditions.

INDIRECT REGULATORS.

Many incubator manufacturers take advantage of the expansion of the heating fluid to regulate its temperature, and insulate the machine so that it will not be subjected to rapid thermal changes in the outer atmosphere. Where the machine can be kept in a closed underground apartment, this works very well, and where the expansion of water is utilized, a constant degree of temperature can be maintained so long as the temperature of the surrounding medium does not change. During the colder months, when the apartment is usually kept closed, the variations in its temperature are not great, and a fairly uniform temperature can be maintained in the incubating chamber. But, when incubating in the early fall and late spring the apartment must be ventilated, and its temperature changing with that of the outer atmosphere, the temperature of the incubating chamber must also follow it to a certain extent, as it is impracticable to construct the walls of the chamber so that they will be absolutely non-conducting. These machines should not be bought with the intention of running them in an ordinary living

room, barn or shed. Under these conditions it would be difficult to keep an even temperature by constant watching, as the regulating mechanism needs adjusting to offset the outer thermal changes.

The principle of utilizing the expansion of water has been patented in a number of combinations, yet I think all but one of these machines have been buried in the dim vista of the past. It is a good illustration of how the regulator does not always make the machine a successful hatcher.

THE EXPANSION OF AIR.

The expansion of a body of air above the water in the heating tank is utilized to a large extent, and has been patented in a number of combinations. Many of the machines using this principle were still-born, or never reached maturity. This principle is open to the same objections as those cited in the case of the expansion of water, with the additional one that air being very compressible, its temperature, as well as that of the water and egg chamber, rises and falls with every atmospheric change. The changes from this cause alone are from two to five degrees, according to the amount of air confined. The manufacturers of the most successful machines who utilize this principle use a very small body of air, filling the tank nearly full of water, the expansion of which is, of course, also added to that of the air. Where there is a large body of water very little or no air is required, and the variations caused by changes in the atmospheric pressure are then reduced to the minimum.

In the application of heat and the regulation of temperature in artificial incubation, it should be made as uniform as it is possible to make it. There are atmospheric conditions that are of equal importance as an even temperature, and which are equally as hard to maintain, and if we allow one condition to vary here, and another there, we cannot expect to get the best results. In fact, unless there is an equal balance between the heat and atmospheric conditions, incubation cannot be carried to a successful conclusion.

CHAPTER V.

VENTILATION.

RESPIRATION exerts an equally important, though not a more powerful influence than heat, over the embryonic development, as over the system of the adult fowl. The essential object of the process of respiration is the absorption or taking in of oxygen from the surrounding medium by the blood, with a corresponding excretion or throwing off of carbon dioxid. At first the germ-cell assimilates the yolk direct. As it develops it gets too large to do without an apparatus by means of which the increasing amount of nutrient material essential to its growth may be obtained, and carried about from part to part, and the waste products disposed of. An extended absorbing or digestive tract, and a system of circulating vessels are therefore developed, and later special excretory organs for the elimination of useless or harmful substances.

The result of the process of digestion is the formation of a quantity of liquid material which can be taken up by the different cells, which are the fundamental form-element of every organized body, and used by them for the process of growth and repair. This liquid is for the most part that red fluid which we are all familiar with as blood.

The circulating vessels are a system of minute tubes, with very thin walls, termed capillaries, and are distributed through the whole organism. These tubes open into others, which are called arteries and veins, and, becoming larger and larger, at length open into the organ we know as the heart. The tubes and the chambers of the heart, with which they are connected, are all filled with blood. The walls of the heart are muscular, and contract rhythmically, or at regular intervals. By means of these contractions the blood which its cavities contain is driven in jets out of these cavities into the arteries, and thence into the capillaries, whence it returns by the veins into the heart again. This is the circulation of the blood.

The ultimate dependence of the embryo for its support and growth on the constant stimulus of this circulating fluid, the blood, demands the maintenance of its vivifying powers by its exposure to the atmosphere as urgently as the mere supply of its deficiency by the absorption of fresh nutriment. That is, the nutritive solution which is formed by the process of digestion, traverses the thin membrane which separates the alimentary tract from the cavities of the vessels in contact with it, and so enters the blood, with which they are filled. Whirled thence by the torrent of the circulation, the blood thus charged with nutritive matter enters the heart, and is thence propelled into the organs of the body. To these organs it supplies the nutriment with which it is charged; from them it takes their waste products, and so returns by the veins loaded with useless and injurious excretions. Those excretory matters are separated from the blood by the excretory organs, of which there are three—the skin, the lungs and the kidneys.

Different as these organs may be in appearance, they are constructed upon one and the same principle. Each, in ultimate analysis, consists of a very thin membrane, with one face free, or in communication with the exterior of the body, and the other in contact with the blood, which has to be purified. The excreted matters are, as it were, strained from the blood, through this membrane, on its free surface, and thence make their escape. Every one of these organs eliminates the same products, viz., water, carbon dioxid, and urea, or some nitrogenous compound of like import. The lungs play a double part, being not merely eliminators of water and excretory products, but they import into the economy a substance which is not exactly either a food or drink, but something as important as either, *i. e.*, oxygen. It is oxygen which is the great sweeper of the economy, which, introduced by the blood, into which it is absorbed, into all the tissues of the organism, seizes upon those organic molecules which are broken down by their work, lays hold of their elements, and combines with them into the new and simpler forms, carbon dioxid, water and urea.

The evolution of the circulating system by progressive changes in the development of the embryo, however, is not completed until the moment of birth. In the early stages of development there is a general or interstitial respiration. The oxygen of the air passing freely through the porous shell and lining membrane, gains access to all the tissues, both of the embryo and yolk. As soon as the nutritive fluid and a central propelling organ are produced, the fluid is driven through the vessels of the vascular area, on the expanded surface of the yolk, and later through the vessels of the allantois, where it is exposed to the influence of the atmosphere through the coverings of the egg. For some time before birth the chick has a mixed action of life, for it breathes, and we can hear it pip and chirp.

All these modifications have reference to the exposure of the fluid to the atmospheric air, either in a pure state, or as contained in all the substances of the egg, through the medium of a thin membrane, and it is obvious that a continual renewal of the air in contact with the outer surface of the membrane is necessary. This is accomplished by the diffusion of the surrounding medium through the down and feathers covering in the egg, and by the oxygen of the air immediately surrounding the egg passing inwards through the shell, effecting exchanges with the carbon dioxid which is expelled. The relative proportions which the oxygen absorbed, and the carbon dioxid exhaled, bear to one another, are determined by the law of the mutual diffusion of gases. By this law the volumes of any two gases which pass through a porous medium to mingle with each other will be in the inverse proportion of the square roots of their specific gravities. The volume of oxygen that passes inward will exceed that of the carbon dioxid which passes outward in the proportion of 1,174 to 1,000. As carbon dioxid contains exactly its own volume of oxygen, it follows that 174 parts, or nearly 15 per cent., more oxygen is absorbed by the blood than is given out in the form of carbon dioxid. A portion of this excess of oxygen unites with sulphur

and phosphorous of the original components of the egg, converting them into sulphuric and phosphoric acids, and the remainder combines with the hydrogen of the fatty matter to form part of the water which is exhaled.

THE DIFFUSION OF GASES.

The fact of the diffusion of gases was first remarked by Priestly. The laws of the phenomena were first investigated by Graham, who gave a life study to the miscibility of the gases. Repeated experiments have well established the fact that gases of a different nature, when brought into contact, do not arrange themselves according to their density—the heaviest undermost, and the lightest uppermost—but they spontaneously diffuse mutually and equably through each other, and so remain in an intimate state of mixture for any length of time.

The tendency of gases to mix with each other is so strong that it will overcome the greatest difference of specific gravity; and, contrary to what a superficial consideration would lead one to expect, the more widely two gases differ in specific gravity, the more rapid is the process of intermixture. This process is termed diffusion, and may be illustrated by means of an apparatus consisting simply of two bottles connected together by a long glass tube. If we fill the upper bottle with hydrogen, and the lower one with chlorine, we shall find, in the course of a few hours, that the two gases have been perfectly mixed together, although the difference between their specific gravities is three times as great as the difference between the specific gravity of mercury and that of water. The chlorine, although thirty-six times heavier than hydrogen, will be found to have made its way into the upper bottle, as may be seen by its green color, while the hydrogen will have passed downward into the lower one, and, when once mixed, the two gases will never separate, however long they may remain at rest.

What has been shown to be true of hydrogen and chlorine is equally true of all other gases and vapors which do not act chemically on each other. The only difference

observed with different substances is the time required to effect a perfect mixture ; but, when once made, this mixture, in all cases, continues uniform and permanent.

Graham observed that the diffusion of gases takes place through porous solid bodies, such as plaster of paris and pressed plumbago, at a rate not very much less than when no such body is interposed. The diffusion or spontaneous intermixture of two gases is effected by an interchange in position of indefinitely minute volumes of the gases, which volumes are not necessarily of equal magnitude, being, in the case of each gas, inversely proportioned to the square root of the density of that gas. These repacing volumes of the gases are termed equivalent volumes of diffusion, and are as follows : Air, 1 ; water vapor, 1.2649 ; nitrogen, 1.0140 ; oxygen, 0.9487 ; carbon dioxid, 0.8091, etc., numbers which are inversely proportional to the square roots of the densities, the density of air being assumed as unity. If the two gases are separated at the outset by a screen having apertures of insensible magnitude, like the plaster plug or the shell of an egg, the interchange of equivalent volumes of diffusion takes place through these apertures, being effected by a force of the highest intensity ; and, if the gases are of unequal density, there is an accumulation on the side of the heavy gas, and loss on the side of the light gas. In the case of air, for instance, on the one side of the screen, and carbon dioxid on the other, a process of exchanging one measure of air for 0.8091 of carbon dioxid, through the apertures, is commenced, and continues until the gases on both sides of the screen are in a state of uniform mixture.

Prof. Henry of Princeton found that a solid bar of lead bent like the letter U, and one end of it put into a jar of quicksilver, which is the only metal fluid at common temperatures, would after some time become so saturated with mercury by capillary action as to convey it out of the vessel to some degree as with a syphon. A lamp-wick draws up oil, or a blotting pad absorbs ink through the same influence. On the same principle is explained the fact that different gases separated by a dry porous

partition, or simply in contact will not remain separate, but will soon mingle uniformly, even against the force of gravity. It is on this principle that the constitution of the atmosphere is everywhere the same, although the two gases composing it are by weight in the proportion of 976 to 1130.

In any discussion of respiratory phenomena in animals, however, it is necessary to bear in mind the fact that all living tissue, and nearly all liquids are capable of absorbing oxygen. Dalton, the distinguished chemist, first noticed that a bubble of air separated by a film of water from an atmosphere of carbon dioxid gradually expanded until it burst; and in like manner a moist bladder, half filled with air, in atmosphere of the same material became in time greatly distended by the insinuation of this gas through its substance. This effect is not the result of simple diffusion, as the thinnest film of water or of any liquid is absolutely impermeable to a gas as such. The result depends first upon the solution of the carbon dioxid by the water on one surface of the film, and secondly on the evaporation into the air from the other surface of the gas thus absorbed.

Similar experiments were made by Drs. Mitchell and Faust, and others, in which gases passed through a film of Indian rubber, entering into a partial combination with the material on one surface and escaping from it on the other. Prof. Graham not only considerably extended our knowledge of this phenomena, but also gave a satisfactory explanation of the mode in which these remarkable results are produced. He recognized in these cases the action of a feeble chemical force insufficient to produce a definite compound, but still capable of determining a more or less perfect union as in the case of simple solution. One of the most remarkable results of this peculiar mode of transfer of aeriform matter through the substances of solid bodies was an ingenious method of separating the oxygen from the atmosphere. The apparatus consisted simply of a bag of India rubber kept distended by an interior framework, while it was

exhausted by a Sprengle pump. Under these circumstances the selective affinity of the caoutchouc determines such a difference in the rate of transfer of the two constituents of the atmosphere that the amount of oxygen in the transpired air rises to forty per cent., and by repeating the process nearly pure oxygen may be obtained.

SECRETION AND EXCRETION.

The functions of secretion and excretion are not mere physical performances, however, but vital processes—combining physical and chemical conditions with vital forces—and consequently exhibit some features quite as inexplicable as life itself. Both filtration and liquid diffusion are observed, but they are modified by the action of living cells. The liquid diffusion of gases involves the passage of a substance through a septum composed of soft colloid matter, or moist membranes, which are impermeable to a gas in the aeriform state. Liquid diffusion may be imparted into the treatment of gases in consequence of the general assumption of liquidity by gases when absorbed by actual liquids or by soft colloids. Water when charged with air holds liquid oxygen and nitrogen in solution; and the latter substances then become amenable to liquid diffusion, and so penetrate animal membranes in the act of respiration.

In natural incubation the eggs are placed in a respirable fluid which surrounds the earth, and forms its atmosphere. This fluid, which is known as the atmospheric air is composed by volume of twenty-one parts of oxygen and seventy-nine of nitrogen. Air also contains 1-2500 volume of carbon dioxid, some aqueous vapor, and small varying amounts of ammonia, nitric acid, zone and organic matter. Its constituent gases are not chemically united, but are mixed mechanically. It may be spoken of oxygen diluted with nitrogen, the oxygen being the active, and the nitrogen the neutral body. When air is inhaled into the lungs the oxygen is separated from the nitrogen, it unites with the carbon in the blood and is expelled as carbonic acid gas, more properly called

carbonic anhydrid or *carbon dioxid* ; a gaseous compound of twelve parts by weight of carbon and thirty-two of oxygen. Diffusing inward through the shell, the air reaches the covering membrane of the egg, which, being thin and moist, offers no serious impediment to its passage inward, the transmission is effected with perfect ease. A partial separation, however, is effected, for, whereas atmospheric air consists of twenty-one volumes of oxygen and seventy-nine of nitrogen, air contained in the egg contains about thirty-three per cent. of oxygen.

If an egg be varnished over before incubation commences, and thus exclude the air, there will be sufficient oxygen already within the shell to suffice for the development of the blastoderm up to about the fifteenth hour of incubation, and the life of the germ is not destroyed until between the twenty-fourth and thirtieth hour, but a fresh supply of oxygen is essential to further development. That is, in order that the nutritious yolk may be afforded to the nutrition of the embryo, it is necessary that it should undergo some changes in which the atmospheric air is concerned, as in the germination of seeds, and during the development of the embryo its blood requires aeration as much as that of the adult animal. In nearly the whole stage of development there is a general or interstitial respiration, or a change essential to life, produced by oxygen in all the substances of the embryo and of its accessory parts, which, as the embryo is more perfectly formed, takes place more actively in particular organs only. As soon as a peculiar nutritive fluid and a central propelling organ are produced, this fluid is exposed on the expanded surface of the yolk to the influence of the oxygen absorbed in the albumen. This blastodermic expansion, or vascular area, throws out villi from its under surface to absorb the yolk, which, in a partially assimilated condition, is transferred to the blood-vessels that ramify over its surface. Thus it acts as the organ of circulation, respiration, and nutrition.

As the vascular area rapidly spreads over the yolk, it continues to act as the chief organ of absorption and di-

gestion, but its importance as a respiratory organ gradually diminishes. In its stead a special respiratory and excretory organ is developed in the allantois. The allantois also serves a nutritive function, for by it the denser portion of albumen is ultimately enclosed and absorbed. It is very vascular, and until the last few hours serves as the chief organ of respiration, the oxygen gaining access to it through the coverings of the egg, with which it is in contact.

The passage of carbon dioxid and hot watery vapor out of the blood, and of oxygen into it, is the essence of the respiratory process, and thus a membrane with blood on one side, and oxygen on the other, is all that is absolutely necessary to effect the purification of the blood. Blood holds in solution rather less than half its volume of gases, two thirds of which is carbon dioxid, less than one third oxygen, and not one tenth nitrogen. It contains rather more oxygen gas than could be held in solution by water, not in a free state, but held in some sort of loose chemical combination with a constituent of the blood. The function of the blood is to supply nourishment to, and take away waste matters from all parts of the body. It is absolutely essential to the life of every part of the body that it should be in such relation with a current of blood that matters can pass freely from the blood to it, and from it to the blood, by diffusing through the walls of the vessels in which the blood is contained.

VENTILATION A VITAL NECESSITY.

Carbon dioxid is constantly generated in the body, and is, therefore, to a certain extent, one of the natural constituents of the blood; but, when not promptly thrown off, its action becomes quickly injurious. When an egg is covered with an impermeable varnish, or the mutual diffusion of the gases on either side of the shell is in any way sufficiently prevented, what is called asphyxia takes place, and the embryo soon dies. This is caused by lack of oxygen and excess of carbon dioxid in the blood. It is not necessary to close the pores of the shell to bring on

asphyxia, but this condition can be effected either wholly or in part by decreasing the proportion of oxygen, or increasing that of the carbon dioxid in the surrounding medium.

The proportion of carbon dioxid naturally existing in the atmosphere may be assumed as inoffensive, but all increase is more or less deleterious. A cubic foot of air of average purity contains a little less than a cubic inch of carbon dioxid. When this amount is increased to eight or ten per cent., the vital activity is sluggish, and when raised to twelve or fifteen per cent. it is speedily destructive to the life of the germ. The cause of this is obvious. Other things being alike, the rapidity of diffusion between two gaseous mixtures depends on the difference of the proportions in which their constituents are mixed; it therefore follows that the more nearly the proportion of carbon dioxid on one side of the membrane approaches that on the other, the slower will be the diffusion of carbon dioxid outward, and of oxygen inward, and the more charged with carbon dioxid and defective in oxygen will the contents of the egg become. And, on increasing the proportion of carbon dioxid in the outer air, a point will at length be reached when the change effected is too slight to relieve the respiratory blood of its carbon dioxid, and to supply it with oxygen to the extent required for its aeration.

Thus we can appreciate the vital necessity of ventilation, or the purification of the air surrounding the egg; which is essentially the dissipation of the carbon dioxid exhaled, and the replenishing of the oxygen consumed. The purification of the general atmosphere is maintained by various agencies of nature. By the law of diffusion all gases intermingle, so that where impurities are set free at any point they tend to diffuse away, and thus become weakened or lost in the great body of the atmosphere. The mixture of large masses of air and the dispersion and dilution of local impurities are also affected by the winds. Gaseous exhalations are washed out and absorbed from the atmosphere by the fall of

rains. The earth's vegetation absorbs and consumes carbon dioxid, while the oxygen is set free. The oxygen of the air slowly burns up the numberless combustible vapors and contaminations which are thrown into it. By these means the earth's atmosphere is constantly maintained respirable and pure.

A CURRENT OF AIR UNDESIRABLE.

As has been shown, in natural incubation a spontaneous intermixture or diffusion of the gases takes place through the coverings of down and feathers, though they are sufficiently dense that any current in an outward and inward direction is prevented by frictional resistance. The latter aids in keeping in the warmth, and also in the rotting of the shell. That is, the carbonate of lime, of which the shell is composed, absorbs moisture. Carbonate of lime, however, is altogether insoluble in pure water, while water saturated with carbon dioxid dissolves 1-1500 part. Water under ordinary circumstances absorbs rather more than an equal volume of carbon dioxid. For its own temperature, the exhaled carbon dioxid is saturated with aqueous vapor; a part of both being condensed by the shell. Thus the ovum itself furnishes the means for the disintegration of the particles of the shell—the carbon dioxid rendering the carbonate of lime soluble in the water or moisture, which is always present. Although a free exposure of the egg to the atmosphere is indispensable to the development of the embryo, yet a current of air is exceedingly undesirable; as the rapid circulation of the atmosphere would be attended with the quick dissipation of the moisture and carbon dioxid.

THE RELATIVE HUMIDITY.

The rapid movement of the air around the eggs has yet other and equally deleterious effects, but they all, however, involve the same principle, *i. e.*: the drier the air, and the more it is agitated, so as to bring fresh currents in contact with the moist surface, the more rapidly

does evaporation take place. The effect of warmth is also to hasten evaporation, but a high degree of heat is not essential to it. At ordinary temperatures, wherever a moist surface is in contact with the air, vapor is formed. This process is called spontaneous evaporation. Aqueous vapor is always present as a minor constituent of the atmosphere, and its amount, which is very variable both at different places on the earth's surface and in the same locality at different times, forms an important element of climate. The process of evaporation is constantly going on at the surface of the earth, but principally at the surface of the sea and other bodies of water.

The amount of vapor which can exist in the air is limited, and depends upon its temperature. It is therefore evident that if the air be saturated with moisture, no more can be vaporized ; and that, in proportion as it approaches saturation, must the process of evaporation be retarded. Whereas, if the air contain but little vapor it can readily take up a large additional amount, and the process of evaporation must be proportionally hastened. In dry, cold days in winter, the evaporation is exceedingly rapid ; whereas, if the air contain much moisture, it proceeds very slowly, even though the air be warm. In other words, space has a capacity for vapor depending upon its temperature, so that if there is a given definite amount or weight of vapor in the air at a certain temperature, the relation which this vapor bears to the whole vapor-carrying capacity of the air at that temperature is very different from the relation which the same amount of vapor bears to the carrying capacity of the air at another temperature. This relation is commonly called the *relative humidity*. Air of a given temperature becomes saturated when there is a certain amount of vapor present, and it can be made to take up no more unless its temperature be raised. Any surplus vapor must be condensed. This vapor present in the atmosphere has, as a gas, a certain pressure, tension, or force, whichever term we care to use to express the same thing ; and this **tension may be as great or greater at the freezing point**

of water, than during ordinary summer temperatures, as the atmospheric air is seldom completely saturated when its temperature is high.

All air found in a natural condition contains more or less of this gas which we call vapor, though it is seldom in a state of complete saturation. Even the dry air blowing over a heated desert contains a small amount, and it this amount which largely influences the rapidity of evaporation.

In natural incubation the eggs are surrounded by a mass of warm air, held entangled and separated from the outside atmosphere by a porous septum of down and feathers, which allow of a reciprocatory movement, or free interchange of the constituent gases and vapors of the inner and outer atmosphere. In other words, the air immediately in contact with the incubating body and eggs becomes warmed. In the gain of heat it expands, becomes lighter, or of a lesser specific gravity than the outside colder and denser air, and tends to flow outward into the latter, which replaces it. It does not, however, carry all its increased warmth with it. That is, in passing outwards, its molecules come in contact with those of the incoming colder air, and imparts to them a portion of its own greater warmth. This loss of heat by the outgoing, and gain by the incoming air, does not quite equalize their warmth within the walls of the septum, under ordinary conditions, but the incoming air gradually gains heat until it comes into direct contact with the heating body, when it has reached its maximum temperature, and then, flowing outwards, loses heat until its remaining warmth is finally dissipated in the surrounding atmosphere. Thus it is seen that the loss of heat is reduced to the minimum, notwithstanding the fact that the atmospheric air surrounding the eggs is being continually changed. The carbon dioxid and organic matter thrown off by the incubating body and eggs, also, as it gains in tension, gradually diffuses outward, being replaced by pure respirable air.

Again, as it has been shown that the porous septum

offers no serious obstruction to the interchange of gases and vapors, it will be seen that the relative humidity or tension of the aqueous vapor in the two atmospheres must be essentially the same, regardless of the difference in temperatures. That is, the quantity of aqueous vapor held in suspension by the outside colder air is as great for its own temperature as the quantity held in suspension by the inner warmer air, and therefore the tension of the aqueous vapor is as great in one atmosphere as in the other. Either an increase or loss in one is immediately felt by the other, and a corresponding movement from the greater to the lesser immediately sets in, and tends to restore their equilibrium. Aqueous vapor will diffuse neither outwards nor inwards when it exists in the same proportion in both atmospheres, but dry carbon dioxid only will be exchanged for dry air, in the proportion of their equivalent diffusion volumes. The incubating body and eggs, however, are continually throwing off watery vapor, which, increasing the tension of the vapor in the inner air above the tension of the vapor in the outer atmosphere, causes a slow diffusion outward, the movement tending to keep up the equilibrium.

Thus the relative humidity of the two atmospheres are always essentially the same, whether the hen nests in a meadow on moist ground, and surrounded by a moist atmosphere, or in a hay-loft and surrounded by dry air. And as she brings out equally as large a proportion of chicks in one place as the other, it is obvious that ordinary changes in the degree of humidity of the atmospheric air has no serious ill effect on the incubation of an egg. And while nature is equally kind in this respect, wherever the hen has found a home, whether she nests in the wild Bengal Jungle or in the northern farmer's barn, the artificial hen has required a varying quantity of supplied humidity, and has received the curses of an exasperated host. It is equally as obvious, then, that in building these artificial hens, commonly called incubators, or hatching machines, that we have transgressed some law of nature, and created an abnormality which we have been vainly trying to

alleviate. The cause of this abnormality is not far to seek.

A DRYING PROCESS.

We have seen that in natural incubation there is a reciprocatory movement, or free interchange of the constituent gases or vapors of the inner and outer atmosphere, through the intervening septum of down and feathers, which keeps the inner air respirably pure, and tends to maintain the relative humidity of the two atmospheres. On the other hand, in artificial incubation the colder outer air, passing inwards en masse through one or more wide apertures in the solid wall of the egg chamber, creates a current sufficient to carry along with it whatever vapors with which it may be charged. Mingling with the inner warmer atmosphere, and coming in contact with the heating surfaces, it gains in temperature, which directly increases its capacity for taking up moisture. Reaching its maximum temperature, it eventually passes outward, still en masse, through the apertures, which again creates a current sufficient to carry along with it its vapors, with any additional gases or vapors it may have gained during its stay in the incubating chamber, and is dissipated in the surrounding atmosphere. This process is continuous, and is kept up as long as the apertures remain open, and the exchange between the two atmospheres is effected in the same manner, that is, by a continuous inward and outward current, whether there is but one or a number of apertures, the only difference being in degree or rapidity of the change, depending upon the area and location of the opening, and the temperature of the surrounding atmosphere. In some machines the activity of exchange between the two atmospheres has been reduced to the lowest point, but with a corresponding loss in the purity of the air within the egg chamber.

The immediate effect of ventilating the chamber in which the eggs are placed by means of more or less wide openings in its walls, is to increase the capacity of the incoming air to take up moisture by raising its temperature, without providing to any appreciable extent for the

absorption of moisture from the exterior atmosphere, and also the dispersion or carrying away of any moisture gained from the eggs placed within the chamber. Thus it is seen that the air around the eggs is in a comparatively dry state, there being a wide difference between its degree of humidity and its total capacity for moisture at its temperature. This state of the air stimulates vaporization, and causes an excessive evaporation of the watery portion of the egg. The egg originally contains about 74 per cent. water, but nearly all of this large amount is as essential to the development of the embryo as the solids, for water is a very large constituent of all parts of the body. The bones contain 130 parts of it in 1000; the muscle, 750; the blood, 795; and it forms, in fact, nearly three fourths of its entire weight. It is evident, therefore, that if the supply of water is diminished by excessive transudation and evaporation the development of the embryo cannot go on.

The rest or movement of the air is of more importance than the difference in the tension or degree of humidity, as influencing the rate of evaporation; for it is found that evaporation is much slower in still air than in a current, with the same degree of humidity. The air immediately in contact with the moist surface becomes saturated with vapor, and a check is soon put to evaporation; if, however, the air be quickly removed as fast as it becomes charged with vapor, and its place supplied with fresh, dry air, the evaporation continues with undiminished rapidity. It is the protection from any current of air that largely prevents a rapid evaporation from the eggs in natural incubation, the diffusion of air and vapor around the eggs being a slow process of exchange in comparison with a current of air.

As incubation progresses there is a special respiratory organ developed, called the allantois, which eventually encloses the whole contents of the egg, and the exhalation of moisture then becomes a vital process. Yet the rest or movement of the air influences the amount of evaporation, even after it ceases to be merely a physical

process; for we find that when a frog is placed in the draft of an open window it will lose triple, or even quadruple the amount exhaled by others placed at a closed window in the same room. It is during the last stages of incubation, and after the exhalation of moisture becomes a vital process, that the rapid evaporation from the surface of the egg, excited by a current of dry air, does the most harm, and which many times ends in the death of the embryo. The cause of the fatal effect of the rapid evaporation is to be found in the drying of the enclosing membranes of the egg; or, in other words, the membrane covering the ovum becomes too dry to take up enough oxygen to suffice for the development and vital activity of the embryo. While moist animal membranes allow the exchange of carbon dioxid and oxygen to be effected with perfect ease, offering no serious impediment to the passage of either gas, dry animal membranes are impermeable to gases.

Although the drying of the covering membranes often cuts short the development of the embryo, and the germs die at various stages of incubation, more generally the embryo suffers the most from this cause from the seventeenth day to exclusion, the greatest number dying about the eighteenth or nineteenth day. By the seventeenth day the albumen is about all absorbed, and the yolk is decreasing in size, and is less fluid. The chick is breathing by means of the allantois which entirely surrounds it, and which is in close proximity to the shell and surrounding atmosphere. As the amniotic water in which the embryo has been immersed is reabsorbed, the sac in which it was contained fills with air, and the chick drawing this air into the lungs, the pulmonary respiration is gradually established. As the pulmonary circulation increases in activity, the circulation of blood in the allantois gradually diminishes, and the allantoic fluid eventually disappears, so that by the end of the nineteenth day the only moisture of any consequence left within the egg is that contained in the substance of the yolk and embryonic structure. There is a pretty timing, however, in the loss

of fluid by the allantois, for it does not normally entirely disappear until within a few hours of the rupture of its coverings by the chick, the membranes remaining moist for some time after, and do not become dry until the chick has been breathing the surrounding air direct for several hours. This is the critical period, for if evaporation be too rapid the allantoic fluid is too early dissipated, and the allantois then is dependent upon the embryo for its supply of moisture necessary to its function as a respiratory organ, and, should the rapid evaporation continue, its membranes very soon become too dry to take up enough oxygen to suffice for the needs of the organism, and death supervenes.

On the other hand, while unduly hastening the drying of the allantois by excessive evaporation is fatal to the life of the chick, an excess of moisture present in the surrounding atmosphere is equally as deleterious, although in the opposite direction; that is, in the prolongation of its functional activity. In other words, by the time the embryo is sufficiently ripe to rupture its coverings the circulation of blood in the allantois is normally quite sluggish, and as soon as the chick gains access to the surrounding air the allantoic circulation ceases, and its membranes become dry. But, should the air be overcharged with moisture, the allantois and blood gains fluid by absorption, and the allantois remains functionally active. Continuing to absorb moisture, the chick eventually gains an excess of water sufficient to interfere with the vital functions.

FOUR PHYSICAL FORCES.

It will now be seen that, other conditions being equal, the degree of humidity ordinarily existing in the atmospheric air is sufficient for successful incubation, providing that the tension of the moisture in the two atmospheres remains the same, and that the rate of movement of the air surrounding the eggs exercises a more powerful influence on evaporation than the usual variations of humidity. In the construction of our hatching chamber, therefore, there are four features of vital importance to be con-

sidered, viz., a non-conducting wall that will protect the eggs from outward changes of temperature; a provision for maintaining the atmospheric air within the chamber in a pure state; the maintenance of as great a tension of aqueous vapor in the inner as in the outer atmosphere for their respective temperatures, and the control of the movement of the air around the eggs.

In natural incubation the purity of the air surrounding the eggs is maintained by exchanges with the outer atmosphere through the wall or septum that intervenes. This wall is composed of down and feathers, which allow of a spontaneous diffusion of gases or vapors through them, while they are sufficiently dense to hold any current in check by frictional resistance. It is therefore obvious that the natural provision for maintaining the purity of the air around the eggs also provides, through the same medium, for the retention of warmth, for an equilibrium between the relative humidity of the two atmospheres, and for the control of the movement of the inner air. And as it is the nature of the fabric of which the wall is constructed that controls the physical forces of incubation, that is, the storage of warmth, and the purity, humidity and movement of the air surrounding the eggs, it is evident that we have not appreciated, or even understood its function.

Knowing the physical forces which this porous septum of down and feathers controlled, and the influence which these forces exerted over the embryonic development, I realized the importance of having the walls of the hatching chamber, which represents the wall of down and feathers, constructed of a similar fabric, or at least of a material which would control the same physical forces. With this end in view I have experimented with many porous fabrics, from a septum with a density of a loose carded wool to a plaster slab, and of various thicknesses, and from a square foot to the entire wall of the hatching chamber composed of these substances. It was found necessary to construct the entire walls of the chamber of a porous material, and after testing nearly every porous

fabric known, that could by any possibility be used for these walls, with various results, I have finally obtained a material that has so far worked perfectly. Machines constructed of this material will be operated the coming winter in our various climates, and if it proves as valuable as it now appears, the poultry fraternity may expect to hear more from it. If not, it will not be put on the market simply to make a dollar. Patents have been allowed which amply cover this principle, and more are pending, looking towards the making of a perfect incubator.

As it is not practicable, however, to adopt this principle to the incubators as now constructed, we will consider how we can approach the nearest to the same results, and show the general indications for the guidance of those who own one or more of the many thousands of hatching machines already in use.

VENTILATING BY DIRECT OPENINGS.

In ventilating by direct openings, repeated experiments have demonstrated that supplied moisture is essential to successful incubation, and the necessary amount is determined by the degree of humidity and the rate of movement of the air within the chamber. The general indications are as follows.

Where top and bottom ventilation both are employed, the circulation of air in the chamber is most rapid for a given area of opening, when the top apertures are about a third larger than the bottom, and as the area of the top openings is reduced, the circulation proportionately becomes less rapid.

In top ventilation alone there is also created a considerable current, as the difference in specific gravity of the two atmospheres gives an added force to the movement of the colder air inward and downward, and the warmer air upward and outward.

Neither top and bottom ventilation combined, nor top ventilation alone has merit enough to be favorably considered as a means of ventilation; there being greater variations in the rate of movement in consequence of

changes in temperature of the outer surrounding atmosphere, than where bottom ventilation alone is employed. As the rate of movement of the air surrounding the eggs has the greatest influence over evaporation, while the more rapid is the process of exchange between the two atmospheres the dryer is the air, it is obvious that where there are wide differences in the rate of movement at different times with the same area of opening for ventilation, we have no condition whatever that is at all constant to base a line of action on.

In bottom ventilation alone the rate of movement and degree of humidity of the inner atmosphere does not remain constant, but the usual variations are not extreme; and after running a few hatches we can in a degree determine the amount of supplied moisture needed for any particular location of the machine. The general principles common to this method of ventilation may be summed up as follows:—

The more rapid the movement of the air, the more rapid is evaporation with the same degree of humidity.

The dryer the air, the more rapid is evaporation.

The rate of movement of the air has more influence over the rate of evaporation than the degree of humidity.

The larger and more numerous the openings, the more rapid is the movement of the air, and the quicker will exchanges be effected with the outer atmosphere.

The lower the temperature of the outer air, the more rapidly will exchanges be effected between the two atmospheres, with the same area of opening.

The more rapid the process of exchange between the two atmospheres, the dryer the air.

LOOSE FITTINGS.

In the first place we shall need to see that the walls are made thoroughly tight. This is an essential feature, inasmuch as cracks in the casing increases the flow of air out of the regular ventilating openings; and as they are seldom noticed, the added ventilation is a source of

much mischief. Thus we find that a machine suddenly ceases to work well under the same apparent conditions that it has been formerly operated with success.

The main reason why two machines of the same make and size do not give like results is owing to this unseen source of ventilation. The manufacturer finding that a certain number of holes apparently gives ample ventilation, cuts the same number in each machine, and does not take into consideration the fact that air is finding its way through the loose fittings of the doors and other parts. His workmen make the fittings close in one, and open in another, and there can be no uniformity in their working. Again, after standing usage for several seasons the inevitable effect of the heat and moisture combined is to open the joinings somewhat, and admitting more or less air, hasten the process of exchange between the two atmospheres, with its consequent evil effects.

To see how much indirect ventilation there is, close all the ventilating openings, and place a lighted candle in the chamber. If the candle goes out in a few minutes, you may rest assured there is not enough indirect ventilation to do any harm. If the candle continues to burn indefinitely after the door is closed, you may be sure it is receiving a continuous supply of fresh air, for unless the candle is receiving fresh air it cannot continue to burn any more than man can live without breathing.

Now, glue heavy paper all over the cracks on the inside that there is any possibility of air getting through, giving the paper a good coat of varnish, so that the moisture will not soften it. If you have covered all the cracks or joinings, and the candle still continues to burn, then look to the doors. You may need to rehang them, facing the jambs with thin felt. Not one machine in ten has broad enough jambs on the doors to make a sufficiently close fitting to keep a large body of air from sifting in.

AMOUNT OF VENTILATION REQUIRED.

After you have the chamber sufficiently tight to put the candle out in a few minutes after closing the door, per-

manently close up all the ventilating openings above the bottom of the machine. The number of holes that there will need to be cut in the bottom to give sufficient ventilation will depend upon how effectually the indirect ventilation has been shut off. Where the chamber receives no ventilation except through the direct openings, the required number of *half-inch holes* in the *bottom* of the machine for each *hundred eggs* to maintain the atmosphere respirably pure, are as follows :—

For the first ten days of incubation, under an outer atmospheric temperature of from 50 to 70 degrees, three holes; under an atmospheric temperature of from 30 to 50 degrees, two holes. From the tenth day to exclusion, under an atmospheric temperature of from 55 to 70 degrees, six holes; under an atmospheric temperature of from 40 to 55 degrees, five holes; and under an atmospheric temperature below 40 degrees, four holes.

I have used two two-inch holes closed by frictionless valves; the latter being operated by a thermostat placed under the machine and influenced by the heat of the outer air. This apparatus regulated the area of the openings as the temperature of the outer air varied, and thus reduced the personal attention required. It is entirely unnecessary, however, to have this attachment when the machine is operated in a closed cellar where the thermal changes are not extreme.

During the first ten days of a hatch the three or four surplus holes can be closed with corks, which may be removed again for the later stages of incubation, according to the outer temperature. A closed underground apartment will never vary more than a few degrees in a day or night, and if the ventilating openings are placed in the bottom the usual variations will not effect the rate of exchange between the two atmospheres to any great extent. The total amount of ventilation can thus be kept approximately constant, and we have something definite to work with. If we ventilate at the top, the rate of exchange for the different temperatures is exceedingly variable, and if we employ both top and bottom

ventilation, the rate of exchange is more variable still. For instance, a half-inch hole in both top and bottom will give as much ventilation, over a limited area, as six holes in the bottom when the outer temperature is at about 70 degrees, and as much as eleven holes in the bottom, under an outer temperature of 35 degrees.

The holes should be distributed evenly over the bottom. The best plan is to put the holes on a line drawn around the bottom parallel with, and eight or nine inches from the edges. Cut the holes at regular intervals around this square.

The number of holes given above is for a chamber which is opened morning and night. There is no way of shifting the position of the eggs or trays without opening the chamber, and unless their position is changed so as to equalize the heat received, it is impossible to successfully incubate a large number of eggs in one apartment.

SUPPLYING MOISTURE.

Having a fairly constant amount of ventilation we can ascertain by experiment the area of evaporating surface needed to keep the air within the chamber from becoming too dry. I say "by experiment," as the instruments usually sold for this purpose are of no service. The wet-bulb hygrometer will vary as much as eight or ten degrees from the actual humidity, while the cheap metal hygrometer is usually extremely inaccurate; and being misleading, is worse than useless.

In putting in pans of water to increase the humidity of the air within the chamber, it will need to be understood that it is the area of the surface of evaporation that determines the rate at which moisture will be taken up, and not the depth of water in the pans. In other words, there will be the same amount of evaporation from a pan of a given dimension, whether it contains one or three inches of water; while there will be four times as much from a pan twelve inches square, as from one only six.

For a machine ventilated as above outlined, a pan of

water four inches square (sixteen square inches), for each hundred eggs for the first ten days of incubation, will be found ample for ordinary situations. From the tenth day to exclusion a pan of water six inches square (thirty-six square inches) for each hundred eggs, will be found about right.

The pan should not be more than a half inch in depth, or whatever its depth, the water should not be allowed to fall more than a half inch below the edge. Evaporation will be the more constant if it is kept at one level, and a small fountain attached to one end is very useful for maintaining it.

The water should be put in with the eggs, and left in throughout the entire period of incubation.

This is contrary to general practice, but a little reflection will show the logic in this method. In the first place, we find that the egg absorbs very little moisture proportioned to the exhalation during natural incubation, and that the loss of moisture is a continuous process extending over the entire period. On the other hand, in the artificial process, as usually practiced, evaporation is allowed to go on more or less rapidly during the early stages of incubation, and after considerable liquid is lost by the eggs, further evaporation is partially checked by increasing the humidity of the atmosphere in the hatching chamber; and at the last, as the embryonic structures have insufficient liquid for the requirements of their vital functions, a large amount of moisture present in the air around the eggs is necessary that they may gain from that source the liquid which they should contain.

As the embryonic development is a continuous process, and a large amount of liquid is necessary at all times for the needs of the vital economy, it is obvious that the liquid present should be ample, and the quantity originally contained in the egg should not be dissipated by excessive evaporation. Where the atmosphere in which the eggs are placed is not too dry, and its movement be not too rapid, the embryonic structures absorb from the contents of the egg, and retain within their membranes

until the last all the liquid they require for their normal activity.

When the hatching chamber is ventilated by direct openings, some moisture will need to be supplied during the entire hatch in order to hold evaporation from the eggs to a normal point and keep the membranes moist; and where the chamber is ventilated as above outlined, sixteen square inches of evaporating surface for each hundred eggs for the first ten days of incubation, and thirty-six square inches for the balance will usually be found sufficient. In particularly dry situations it may sometimes be increased very little to advantage; and on the other hand, in very moist climates, a lesser area of evaporating surface may answer. Whatever is needed, however, should be put in at the commencement of incubation, and maintained throughout the hatch. Even where the relative amount of moisture is maintained uniform throughout the period of incubation there will be a comparatively larger amount of evaporation from the egg during the initial stages of incubation, and as more and more liquid is lost by the egg, and the embryonic structure takes up a large amount for the formation of the amniotic and allantoic fluids, evaporation becomes less and less active.

It is best to set the pans an inch from the bottom of the chamber; and in the centre, or along a line in the centre, at equal distances between the two ends. If there are hot pipes in the bottom, as there are in some machines, in no case set the pans on the pipes. Moreover, the pans in this case should be set in wooden frames made of seven-eighths pine stock, the top being on a level with the top of the pans. This will protect them from the radiant heat given off by the pipes, which otherwise would to a certain extent govern the temperature of the water. The temperature of the pipes varies with that of the outer atmosphere, and the number of fertile eggs incubating; and their temperature should not be allowed to govern that of the water in the pans, as evaporation will be greater or less according to the tempera-

ture of the water. Do not set the small pans over a ventilating hole, as their temperature would then be affected by that of the incoming air.

In removing the large moisture pans that usually come with the machine and set on the hot pipes in the bottom of the chamber, do not forget to cover up the pipes again. If this is not done, the radiant heat striking the under side of the egg breaks up its natural arrangement, causes undue chemical changes, and the embryo seldom lives to be excluded. A three-inch strip of seven-eighths pine stock made in a frame and laid over the pipe will effectually shut off the radiant heat from it.

For a smaller number than one hundred eggs it is better to give both sufficient ventilation and moisture for that number, but where there is about one hundred eggs less than the full capacity of the machine, or a multiple of one hundred, a corresponding number of holes may be closed, and a corresponding number of moisture pans removed.

Whether there has been the correct amount of moisture or not can be judged approximately by examining an egg or two about the eighteenth day. If the membrane separating the chick from the air space at the broad end of the egg is clear white, dry to the touch, and binds the chick firmly in the small end, its head being closely pressed under its wing, and its feathers nearly dry, there has been too little moisture. More should now be put in to bring this hatch to maturity, and in the next one put in a little larger pan.

If, upon examining the egg, the chick seems to be too large, the yolk still of considerable size and very liquid, there has been too much moisture. The heat of the chamber should be raised a degree or two and more ventilation given to exclude these chicks, and in the next hatch use a little smaller pan of water.

In a normal development the chick will occupy about five-sixths of the space within the shell; the inner membrane of the air space will have a dark tinge, and feel soft to the touch; the head will be but loosely pressed beneath

the wing; the feathers decidedly moist, and the remaining yolk about twice as thick as in a fresh egg. The albumen will have about all disappeared, and the yolk-sac and contents will about fill a table-spoon.

After running two or three hatches, the amount needed for the location can be approximately determined. If the amount of ventilation is maintained uniform as above outlined, the usual variations in the degree of humidity of the general atmosphere will have no appreciable effect; while, if the area of the ventilating openings remains the same for all temperatures, no system of supplying humidity can be devised that will give uniform results.

CHAPTER VI.

THE INCUBATOR AND BROODER.

BEFORE a hatch is started, it is very important that the machine is placed in an apartment which has a normal atmosphere, and protected from rapid and extreme outer thermal changes. By a normal atmosphere, I refer to an atmosphere as ordinarily found out of doors. In other words, the air should be fairly pure, and contain a moderate amount of moisture. In a wet cellar, for instance, which contains rotten wood, decaying vegetables, etc., we would not call the air normal, for upon examination it would be found to contain a high degree of humidity, and too large a percentage of carbon dioxid and poisonous organic matter.

While a chamber partially underground like a cellar is one of the best places to put a machine, it should be dry, clean and sweet, with some ventilation. In cold weather, where there are two or three windows in the apartment, no direct openings will be needed, as more or less air will find its way in between the fittings as ordinarily made. In moderate and warm weather there will need to be direct ventilation. The *smell* of the apartment is a good indication as to whether it needs more light and air or not.

The main advantage of an underground room is that it does not quickly feel the extreme temperatures in the outside general atmosphere. The temperature of a well-insulated cellar will never fall to the freezing point, and will seldom rise to 80 degrees, while the thermal changes are slow in taking place. Where the temperature of the hatching chamber is regulated by the expansion of the heating fluid, if it is to be maintained uniform, it is absolutely essential that the machine should be placed in an apartment with a fairly steady temperature, as the temperature of the hatching chamber will go up and down with the outer thermal changes, the temperature of the

heating fluid remaining constant. If the outer thermal changes are rapid, it is impossible to maintain an even temperature in the chamber, however closely the machine is watched.

Some incubator manufacturers have been slow in insisting upon their machine being placed where it would be insulated from the sudden thermal changes in the general atmosphere, as others advertise with much braggadocio that an even temperature can be successfully maintained with their machine under all conditions. For the same reasons nearly all manufacturers advertise their respective machines to meet the various other requirements, and to hatch 100 per cent of the fertile eggs. With but one exception the most successful machines now on the market are those regulated by the expansion of the heating fluid, and even this machine gives the best results when insulated against rapid and extreme thermal changes, as all incubators with direct ventilation must. All incubators have their limitations, and the beginner should be made acquainted with them, and not left to addle his quota of eggs before he finds them out.

NORMAL EGGS.

Our next consideration is to secure hatchable eggs. There has probably been less thought given to this part of poultry raising than to any other. The prevailing opinion seems to be that an egg is an egg, one being as good for incubating purposes as another. Nothing could be farther from the truth. Occasionally we hear a poultryman grumbling about "watery eggs," but there are very few as yet who feed their breeding stock with any purpose in view other than to secure all the eggs possible. This, perhaps, is well enough when the eggs are intended for market, and we do not intend to again breed from the hens that are over-forced; as consumers do not as a rule appreciate the difference in quality of eggs, but only discriminate in favor of size and color. When customers are willing to pay for quality as well as quantity, there will be no longer any excuse for this

practice. If we intend the eggs for hatching, however, too great care cannot be taken that the breeding stock is not over-forced, and that it is properly grown and well selected. This latter is a vital point, as without strong, vigorous stock we cannot secure eggs that will exclude vigorous chicks when they do hatch, no matter how well the parent may have been nourished. Breeding from other than vigorous, well-selected stock should not be thought of. Over-forced, debilitated or inferior stock should be discarded from the breeding pens.

Unless the birds are well matured, the first batch of pullet's eggs will not hatch well, and the birds secured from such eggs will never flatter the breeder's vanity. Again, the hens cannot be expected to continue indefinitely, month after month, producing eggs that are well vitilized. While after four or five months steady laying the eggs may still be fertilized, the germs are not strong, the food-yolk is defective, and the germs die at all stages of incubation. Those chicks that are excluded are undersized, and show the debilitated state of the parent.

In the case of the mammal, the foetus draws on the mother's vitality during the whole period of gestation, and it has a very good chance to be born alive, whether or not it has the vital power to sustain life to maturity. But the case is different with the bird. Here the transformation of the ovum into the body of the chick does not take place within the mother, but is excluded to be developed externally, and is supplied with yolk-food for the development of the embryo. If this yolk-food is defective, either in the composition or arrangement of its constituent parts, or in the texture of its covering membranes, the germ consequently suffers.

The normal egg contains all the elements necessary for the development of a perfect chick, and in such an amount and arrangement as to insure its exclusion; but there is a limit to the amount of forcing a hen will stand and continue to exclude normal eggs. Not only is there a limit to the number of normal eggs a hen can be forced to lay in a given time, but there is also a limit to the total num-

ber she will lay before having a somewhat protracted period of rest. The number of normal eggs a hen will lay, and the period in which she will exclude them, undoubtedly varies with individual birds, as well as with different breeds. Without the data of a carefully conducted series of experiments, no definite statements can be made. The indications are, however, that the majority of the breeding stock has been over-forced during the laying season, and that period too long protracted. Eggs that will not exclude 90 per cent. of the fecundated germs when incubated by a faithful sitter, not too long broody, are comparatively unprofitable to incubate, either in point of view of cost, or vigor of the stock secured. There is too great a mortality among the chicks when the percentage of hatch is low, and their growth is too slow and uncertain.

UNIFORM TEMPERATURE AND VENTILATION.

In running an incubator, the leading feature, and the hardest to secure, is an even temperature. This would not be the case had we a good regulator, but we have not. Not only has many hundreds of dollars been spent in experimenting, trying to get a good heat regulator for an incubator, but many thousands of dollars have gone in like manner to secure a heat regulator for other purposes that would be controlled by dry heat, and which would keep the temperature constant to a degree under all reasonable conditions. It is absolutely impossible to make such a regulator that will be delicate enough to hold the heat to a degree, powerful enough to do the necessary work, and simple and inexpensive at the same time. This has been and still is the aim of experimenters, but it must only meet with failure in the future, as it has in the past. Whatever means is employed to regulate the temperature of the hatching chamber, it is absolutely essential that it should be kept within narrow limits. The heat and atmospheric conditions must balance one another, and, if they do not, incubation cannot be carried to a successful exclusion.

My meaning is simply this : Evaporation from the egg must be held at such a point that the fluids in the embryonic structures are ample to keep the membranes moist up to the time of exclusion, and the rate of evaporation is not the same under any two degrees of temperature. Eggs may be successfully incubated under a temperature that will exclude the chick by the beginning of the nineteenth day, or under one that will not exclude the chick until the twenty-second. The most vigorous chicks will be produced when the eggs are incubated under a temperature that will ripen the embryo by the close of the twentieth day, and any variation from this temperature will proportionately effect the vitality of the chicks, and lower the percentage of the hatch. If we have a rate of evaporation to balance the temperature for a twenty-day exclusion, this rate of evaporation will not answer for a nineteen or twenty-one day ; there being too great an amount of evaporation for a nineteen-day, and too little for a twenty-one day. In neither case will many of the eggs hatch, but if we supply more humidity (the rate of movement of the air remaining the same) for a nineteen-day, and less for a twenty-one day exclusion, we will have a chance for a fair hatch. If we have a degree of humidity to balance a twenty-day exclusion, and then raise or lower the temperature half a degree, it will injuriously effect the hatch, while a greater variation will ruin it. A constant variation of a degree in temperature will have no injurious effect, but if the temperature is permanently raised or lowered a degree, the atmospheric conditions for a twenty-day exclusion will not answer.

Therefore I say that the heat and atmospheric conditions must be balanced. If the rate of movement of the air around the eggs is maintained fairly constant, as it may be when employing bottom ventilation alone, a considerable variation in the degree of humidity can be withstood under a temperature sufficient to exclude the chick in twenty days. The bulk of the poor hatches in the past can be directly traced to a wrong temperature and a varying amount of ventilation, while they have been at-

tributed wholly to a wrong degree of humidity. No attempt whatever has been made to maintain a constant amount of ventilation, as the necessity for it has not been appreciated. Both too high and low temperatures have been maintained, partly through a lack of knowledge of the actual temperature of the eggs, and to meet the various requirements of different atmospheric conditions.

It has been universally believed that evaporation from the eggs could only be controlled by controlling the humidity of the air in the hatching chamber. The humidity of the air is but one controlling factor, however, as with the same degree of humidity evaporation will be slow or rapid according to the rate of movement of the air, while it is not the same under any two degrees of temperature, and the constant variation in these two factors is the cause of the extremely varying results. With a due appreciation of these facts artificial incubation should be more successfully prosecuted in the future than it has been in the past.

Evaporation is mainly influenced by the rate of movement of the air within the hatching chamber, and secondarily by the degree of humidity. The rate of movement of the air is controlled by the area and location of the ventilating openings and temperature of the outer atmosphere. The degree of humidity cannot be maintained constant when maintaining a constant rate of movement of the air, and it is not necessary that it should be. The first consideration is to secure a constant rate of movement, and then keep the air from becoming too dry. This is practically all that is necessary in supplying humidity when the rate of movement of the air is maintained constant.

In natural incubation the degree of humidity of the air around the eggs is slightly higher than that of the general atmosphere, as considerable moisture is being constantly given off by the incubating body. But in the incubating chamber, ventilated by direct openings, the incoming air practically undergoes a drying process, its temperature being raised, which directly decreases the

tension (not lessening the amount) of its aqueous vapor. The tension of its vapor being decreased, the air is now capable of taking up a large additional amount. The air within the chamber would immediately gain sufficient humidity directly from the outer atmosphere to keep the tension of the vapor in the two atmospheres at a balance, did not the continuous current of air passing through the apertures partially prevent it.

The rate of movement of the air through the apertures controls the amount of vapor that will pass inwards independently of that which is carried with the ingoing air—the greater with a slow, and a lesser amount with a rapid rate of movement. The rate of movement of the air through these apertures is the greatest when there is an opening in both the top and bottom of the chamber; a slightly lesser rate of movement when there are but top openings; and the slowest and most uniform rate of movement when there are openings only in the bottom. The tension of the vapor in the inner atmosphere therefore corresponds more nearly to that in the outer air when bottom ventilation alone is employed, and with the addition of a source of supply from within, the tension of the vapor around the eggs in an incubating chamber can be maintained on a par with that in natural incubation. By regulating the area of the ventilating apertures we can offset, to a certain extent, variations in the degree of humidity and rate of movement of the air within the chamber, caused by different rates of exchange between the two atmospheres under the different external temperatures; while the usual variations of humidity caused by variations in the general atmosphere will have no serious ill effect.

THE TEMPERATURE.

The bulb of the thermometer should be placed upon a fertile egg, and its temperature maintained as nearly uniform as possible at 102 degrees during the warm weather, and 102 1-2 degrees during the colder. This will keep the great mass of the egg at a slightly higher temperature

during the initial stages of incubation than it attains with the hen incubating, but it is to be remembered that in the latter case the heat is applied directly to only a small portion near which the germ lies, while in the hatching chamber the heat is equally applied to the whole upper half, while the under surface receives secondary radiation of nearly equal value from the trays. Thus, in order that the germ may receive sufficient heat to duly stimulate its vital activity, the great mass of the egg will need to be warmed to 100 or 100 1-2 degrees at first. As more and more heat is generated in the egg its temperature will gradually rise above that of the thermometer. When the bulb of the thermometer is placed on a fertile egg, their relative temperatures are not always the same, but the usual variations are not so irregular and extreme as when it is placed in other positions.

TURNING THE EGGS.

The eggs should be turned twice a day up to the nineteenth day. If this is not done many of the germs will dry fast to the shell during the early stages, owing to the influence of a high temperature, and the breaking up of the arrangement of the albumen, which then allows the germ to be pressed upward with some force. Then again, during the initial stages of development, the germ gets its oxygen from the albumen. In fact, it gets its supply of oxygen from this source until the allantois attains some considerable size, the vessels in the vascular area absorbing the oxygen from the albumen, in the same manner as the blood-vessels in the gills of a fish absorb the oxygen from the water in which it lives. Turning the egg brings a fresh surface of albumen in contact with the shell, thereby causing a more rapid absorption of oxygen from without, and also brings a fresh surface of albumen in contact with the vascular area. ○

When the egg is not turned during the later stages of incubation, the embryo does not attain a natural position, and has little chance of being excluded. When turning the eggs during cold weather, it should be done as quickly

as possible, so that the eggs and chamber lose but little warmth.

The position of the trays should be shifted at least once a day, so as to equalize the heat, as, in no large machine, can the eggs be heated sufficiently near to a uniform temperature as to warrant leaving them in the same relative position throughout the hatch.

TESTING THE EGGS.

The unfertile eggs should be tested out about the tenth day. By the tenth day the fertile germs will darken a considerable portion of the egg, and those eggs can be readily detected. It is difficult to distinguish between a live germ and an addled egg before this time through the darker colored shells, while there is no particular advantage to be gained in an earlier testing. An unfertile egg at ten days will be as clear as a fresh egg; an addled one will appear clouded throughout, with dark spots; and a live germ will give the greater portion of the egg an even dark appearance, which, under a very strong light, will have a reddish tinge. A little practice will enable the novice to detect the fertile eggs with readiness.

THE EXCLUSION.

During the period of exclusion of the chicks the machine should be kept closed, and its temperature at its full height. There is no time that a hatch can be injured so much by cooling the chamber and eggs as when the chicks are coming out. If the trays are divided off to break the hot-air currents, leaving about fifteen eggs in each apartment, the chicks will not move about so much as when they are exposed to a current of air, which they are extremely sensitive to owing to their moist condition. The temperature of the trays is none too great for them, though after a large number are out, they will need more air. For this purpose a sliding valve should be provided in the bottom. An opening, three by six inches, is ample for 150 chicks. It can be fitted with a valve on either the inside or out, but there

should be some means of working it without opening the door. It is a good plan to give a little more ventilation as soon as the chicks begin to pip, increasing the amount as they are excluded. They require plenty of fresh air at the time of exclusion, and, if they have been incubated under normal conditions, the added ventilation will have no ill effect if the temperature is kept up. Too much air, however, should not be given before the chicks are all excluded, when they should have sufficient to keep them from panting. Leave them in the trays for at least the first fifteen hours.

THE BROODER.

Before removing the chicks from the incubator, have the brooder heated to about 95 degrees. Care must be taken for the first few days that its temperature does not fall below 90 degrees, after which it may be gradually lowered to 70 degrees by the third week. If the chicks get chilled during the first few days they will never thrive, if it does not prove fatal. If they should get chilled, however, keep the temperature of the brooder up to about 100 degrees for three or four days, giving a light feed of bread and milk. By this means I have succeeded in bringing a brood out of the dumps when there seemed to be little hope for them.

It should be remembered that the chicks will need to be gradually hardened off, and that the temperature of the brooder should not be brought down in jumps of ten or more degrees at a time. In cold weather the brooder should be large and roomy if the chicks are expected to do well. Some of the small affairs that are sold for brooders are of no service after the first few days, and consequently have no real value.

THE FIRST FEEDS.

Without an exception bread and sweet milk make the best food for a day or two, if not for the first two weeks. At the time of exclusion the crop, gizzard and intestines are filled with uric acid and other excretions, of which

they should be cleaned. I have fed on nearly every food usually employed, and killed and dissected by the third day over one hundred chicks. Of all the foods experimented with, bread, softened with sweet milk, clears the crop and gizzard, and starts the chick growing the quickest. The first feed may be given about the eighteenth hour. The feeding of nothing but a soft food such as bread and milk requires too much time to be profitably continued long, but, where it can be obtained at a low cost, skimmed milk can be profitably employed as a substitute for water in mixing the soft feeds given.

THE CONCLUSION.

In bringing this work to a close, I would remind the reader that the incubation of an egg is the commencement of a life, and therefore is as complex as life. To thoroughly understand its various phenomena we must take as broad a physiological view of it as a doctor does of the human economy; and we should recognize a normal or abnormal development, and remedy a defect in our machine as quickly as an M. D. would recognize a fever and apply the proper remedies. This knowledge can only be gained by close observation, experiment and study.

And now kind reader, if facts have been given that do not bear out some of your theories, or are against some device you have set great store by, remember that exact data has been given upon which to base correct theories or build up a better apparatus.

THE END.

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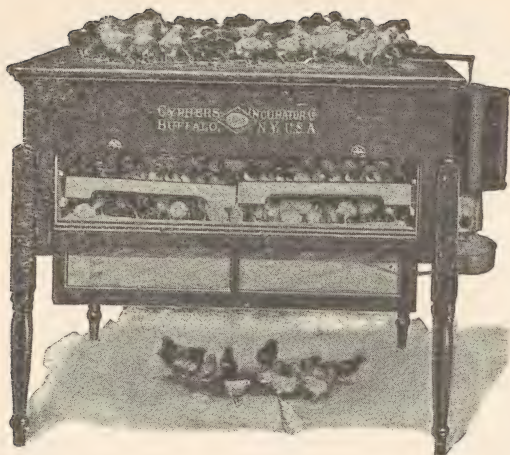
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